Ecological Issues in a Changing World

Status, Response and Strategy

Edited by

Sun-Kee Hong, John A. Lee, Byung-Sun Ihm, Almo Farina, Yowhan Son, Eun-Shik Kim and Jae Chun Choe

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PREFACE

The 8th International Congress of Ecology was held in Seoul, South Korea in August 2002, and was hosted by the Ecological Society of Korea. The Congress theme was 'Ecological Issues in a Changing World', and this volume includes selected contributions to illustrate some of the important topics which were discussed during the Congress.

Problems of scale have exercised the minds of ecologists for many years, and will continue to do so into the future. This volume deals with this subject and with mathematical approaches to improve our understanding of complex ecological systems. The book also concentrates on monitoring the responses of ecosystems particularly to human impacts upon them. The importance of spatial separation of function at both the landscape and ecosystem level forms an important theme. Finally, this special book focuses on large-scale issues, discussing in particular important applied ecological problems and how these can be managed through a variety of planning processes. Many examples of major ecological problems in the mainstream ecological literature are drawn from Europe and North America. In contrast, many of the most pressing ecological problems are to be found elsewhere in the World.

The 8th INTECOL International Congress of Ecology set out in part to help to redress this situation. Many of the sessions discussed major problems of the Asian region with a view to their wider appreciation in the ecological community at large. This volume continues this process drawing many examples from China, Japan and importantly South Korea. The expertise of ecologists from these countries, the range of the ecological problems which they face, and their solutions to them provide the major substance of this book. Those of us from other parts of the World who attended the Congress were fascinated by the range of major ecological questions being addressed by our Asian colleagues. This deserves to be more widely appreciated in the ecological community. This volume is an important step in this process.

This volume is composed of four parts according to scale, objectives and application of modern ecological research. Part I covers emerging concepts and models in the ecosystem complex and in the landscape. Part II. Biological responses to environmental changes: pattern and process, Part III. Ecological networking and restoration technology: theory and practice, and finally a summary of 8th INTECOL Congress and possible future directions are covered in Part IV.

In “Part I. *Concepts and models in the ecosystem complex*” each chapter discusses several emerging theories and their ecological methodologies. At this point in time our understanding of ecosystem configuration, ecological function and dynamics is advanced by spatial analyses and models, and by interdisciplinary theories and concepts (esp. ecosystem complexity, landscape ecology and spatial

models). The advancement of new concepts and the development of spatial analysis technology help us to understand ecosystem complexity and major global environmental problems. This section covers concepts and theoretical model in the spatio-temporally-different ecosystems and their importance for scaling up from ecosystems through the human-landscape system scale to the global scale.

Part II. "*Ecological responses in global environmental change: pattern and process*" focuses on ecological responses to major environmental change factors. Ecological responses to these factors are potentially very important indicators of ecosystem health and environmental conditions. These 8 chapters discuss the cause and consequence of ecosystem stability and health in the light of the ecological responses of organisms. They also deal with scaling from ecosystems to the global level in considering the impacts of climate change and pollutants. Practical models and solutions to ecosystem stability are also discussed by world. Part II also contains several papers discussing biological conservation and biodiversity monitoring techniques. Conservation of biodiversity is major current issue. Although the threat to biodiversity is well recognized, the crisis still continues in many of the World's biomes. This section covers several ecosystems which are highly threatened by recent land developments. The strategy of maximizing the conservation of biodiversity is often very concerned with habitat or landscape conservation surrounding target organisms. Therefore, biodiversity conservation practioners are trying to understand habitat structure and related ecological functions. Issues of biodoversity and habitat conservation are strongly correlated to each other and are also important for human health and the environmental beauty of the earth. This section also discusses the interface between ecological and human sociological issues.

Part III. "*Ecological networking and restoration technology: theory and practice*", considers habitat networking problems associated with expanding human settlements and the exploitation of natural resources. Urgent issues are concerned with ecological restoration perspectives at both the ecosystem and landscape scale. The need for new environmental impact assessments of human-dominated ecosystems is explored. The need to balance ecosystem conservation and human development in several landscape types (urban-suburban, agricultural, watersheds and rivers) is explored.

In this part, new theories of landscape planning, the restoration technology of land management and ecological engineering are suggested as new methodologies of environmental impact assessment and ecosystem information. The papers show new paradigms of "sustainable land use and society" and the vital importance of global ecology and networking in a changing world.

Part IV. The *Epilogue* deals with the necessity of international networking by active co-operation in order to solve the environmental problems. The International Congress of Ecology in Seoul involved the participation of many international and domestic academic associations. Their roles and strong support were major factors leading to the success of the Congress. Notable examples include the International Association for Landscape Ecology (IALE) which was an important supporter. During the Congress, this group showed new solutions of environmental problems at

both the local and the global scale. The Long-term ecological research network (LTER) is another international organization working at both the local and global scale. The new methodologies in several fields of ecology were discussed, especially in consideration of USA and Chinese LTER sites.

One of the most valuable outcomes from the 8th International Congress of Ecology was the establishment of the "*East Asian Federation of Ecological Societies* (EAFES)". This is a most important development for ecologists in the region, leading to much greater co-operation and interchange of ideas. The mutually beneficial activities of EAFES and INTECOL will help such co-operation between ecologists world wide, and will be important in addressing the major ecological problems which will confront us in the 21st Century.

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Color Plates

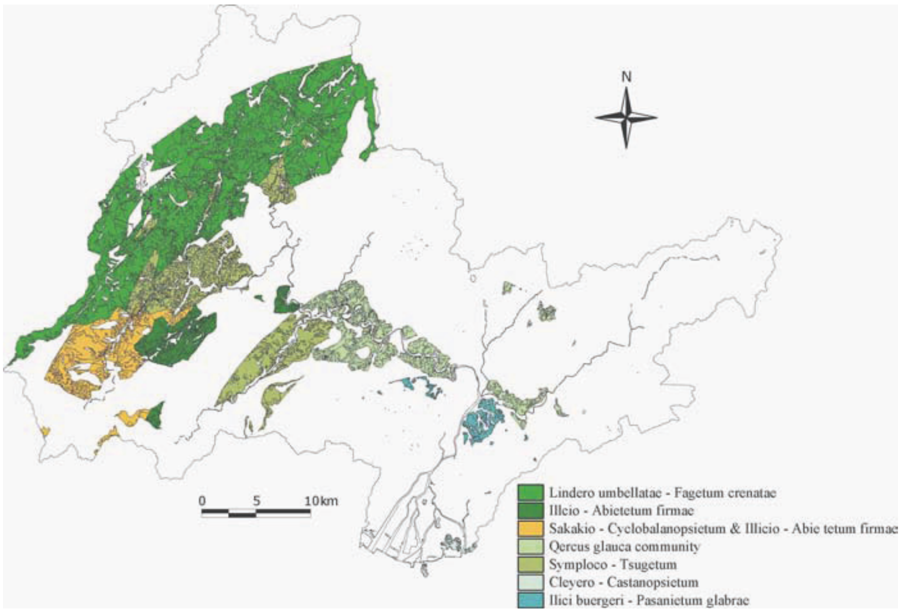

Figure 5. Potential distribution of actual geotopes appropriate for carrying the restoration project of natural forest ecosystems
(From Chapter 5, by N. Nakagoshi et al., page 308)

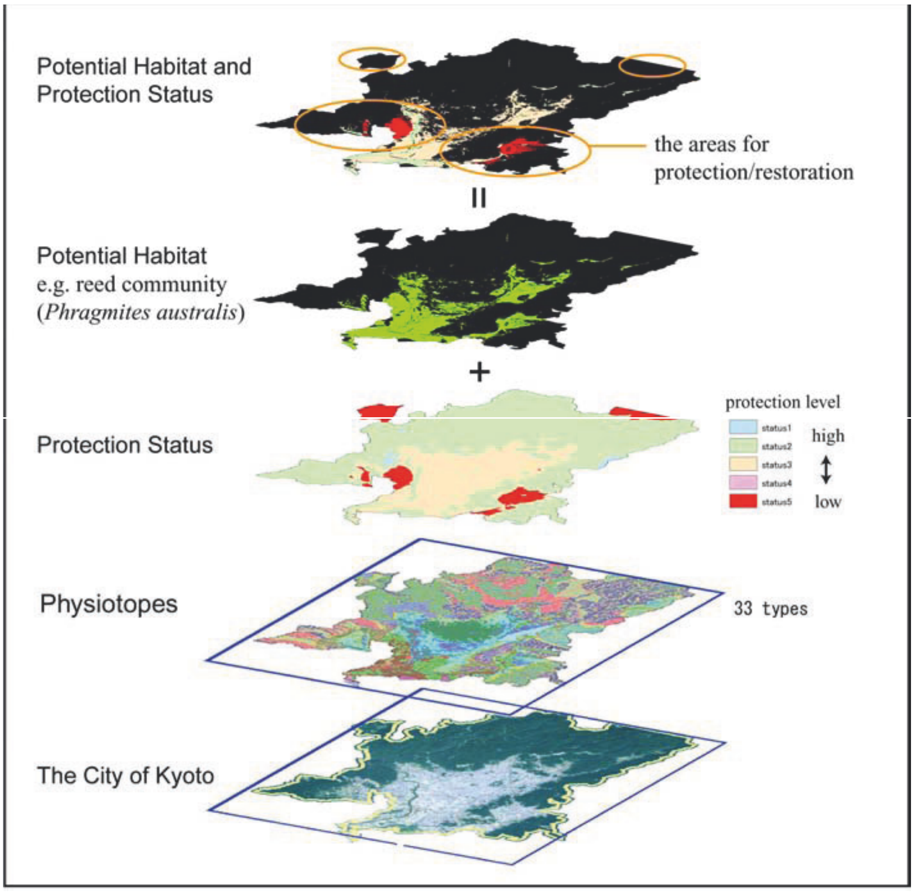

Figure 3. Gap analyses using potential habitat to identify the areas for protection and restoration in the city of Kyoto (Imanishi et al. unpublished). Potential habitat for each vegetation was estimated using 33 physiotope classes and existing locations. The figure shows the case of reed community, one of the remarkably reduced communities. Potential habitat overlaid with protection status could help us to identify the areas not only for protection but also for restoration.(From Chapter 20, by Y. Morimoto, page 331)

Figure 4. Comparison of EXPO'70 site in 1970 (left) and 2000 (right). Reclaimed and afforested in 1972-76 under the concept of a self-sustaining forest ecosystem in the urban area. (From Chapter 20, by Y. Morimoto, page 334)

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PART I

CONCEPT AND MODEL IN ECOSYSTEM COMPLEX

ALMO FARINA & SUN-KEE HONG

CHAPTER 1

A THEORETICAL FRAMEWORK FOR A SCIENCE OF LANDSCAPE

1. INTRODUCTION

Human intrusion is growing at an exponential rate modifying structure and functions of many ecosystems (loss or reduction of habitats for species, loss of biodiversity) and reducing the ecosystem services. Many modifications are not immediately visible creating an ecological debt dangerous for the entire planet (Tilman *et al*. 1994) and reducing the possibilities for new biological aggregations.

Human activity that proceeds at an accelerated rhythm affects several of the environmental constraints that have regulated the biological adaptation) as well as the physical dynamic of the land crust.

In particular human activity at difference of other biological processes occupies a system of meta-domains that ranges from the biological realm to the mind realm through a huge possibility to invent new tools that enlarge the sphere of "competencies" touching the functioning of individual organisms, their aggregations (population, communities) and supporting systems (ecosystems, landscape), until the bio-physical processes. Such tools are the result of human capacity to handle things but also to "create" by mental processes new "virtual" conditions that finally are translated in a material domain. The mind domain is largely used to create physical domain by a self-reinforcing closure.

Ecology is a relatively young science that enters into the center of the storm of environmental modifications without the necessary tools to face new and unpredictable effects of the thermodynamic disturbance (manipulated by energy), autopoietic processes (*sensu* Maturana and Varela 1980) complex interactions.

The aim of this article is to present new epistemological possibilities for a theory that fill the gap between the separate knowledge that to day reduce the capacity to adapt our life style to ecological processes. The ideas that will be presented are an attempt to create a more general framework in which landscape is considered per se sufficient to justify a separate science.

2. THE NEED FOR A NEW EPISTEMOLOGICAL MODEL

Modern science is based on reductionistic paradigms that divides in parts the components of the systems. This approach has allowed extraordinary progresses in many directions from health sciences, to computing to biochemistry.

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The separate knowledge have been grown very fast especially during the second half of the 20th century, but these knowledge are not sufficient to understand the complexity of the earth processes, especially the interactions between noosphere and the ecosphere. Such interactions produce emergent effects that can not be controlled by applying partial approaches. The earth degradation appears as an emergent phenomenon that can not be explained simply by the summation of the separate disturbances. The defeat of the modern science to solve the problems posed by the life style of our society (more and more complex because more and more connected) oblige us to turn very quickly moving into the direction of a new ethic in science (Haber 2002) that we consider the starting point of every real paradigms shift (*sensu* Kuhn 1962).

But, if ethic in science as well as in the society is absolutely necessary to define the limits and the quality of our habits, at the same time is essential to create new tools able to investigate the complex relationships between human sphere and the environmental sphere. It is not enough to investigate the natural processes, it is urgent to understand better the relationships between human "world" and the natural "world" and not just using general declarations and principles but by direct actions influencing natural as well as human processes (Farina 2003).

Every science is born to explain phenomena, and the human interference with natural system needs definitively a specific science. It seems clear that human domination of the Earth requires new approaches to understand the mechanisms located at the fringe between physical-biological and cognitive interfaces.

It is our responsibility to give up to the apparent advantages of traditional sciences and to try ways to explore new possibilities for the future. The scientific society in general is very prudent before to change direction and we expect significative resistance to the idea to found a new science based on the landscape (see also Lawton 2001).

3. THE THEORETICAL BASIS OF A NEW SCIENCE

Often theory is necessary to demonstrate an assumption, but in our case theory is necessary to identify a part of the complexity that we decide to investigate and to understand better for an ethic and efficient management. We understand complex system only by using a paradigmatic framework, complexity di per se is not self explicit.

In many cases complexity means a great number of interactions and some disciplines are studying the way every single process is linked to all others. The believe that complexity is like a giant watch made by millions of wheels and gears is wrong. Complexity could be imagined like an enormous number of soap bubbles of different dimension that interact each other, melting in larger bubble and contemporary the extinction of some and the appearance of new ones. Bubbles are related not by fixed mechanisms, but the mechanisms are in action to create and maintain the single bubble.

Ecosystem paradigm has been central and standard idea for several decades in developing the ecological theories (Muller 1997, Odum 1983, Holling 1986), but as

recently argued by Bob O'Neill (2001) is largely obsolete and in any case needs new conceptual integrations

Contemporary to the crisis of ecosystem conceptualization, the new paradigm of the landscape was developed in Europe (Naveh and Lieberman 1984) and in United States (Forman and Godron 1986) disclosing a new era for field research and applications (Turner *et al*. 2001), and contributing to the formation of a solving-problem science (Farina 2000a).

The fortune of this new concept is based on the general principles by which at difference of the ecosystem paradigm, the landscape paradigm considers space as a physical dimension of processes and patterns, and spatial arrangement of objects important for the functioning of the entire system. While to understand processes are necessary sophisticate tools, to understand patterns is a more easy task. Every body can recognize a corn field and appreciate the geometry and the relative position into a mosaic of other fields. An outstanding contribution to the development of this ecological discipline has been done by the introduction of the GIS practices and remote sensing techniques on one side, and by the development of spatially explicit models on the other side (Farina 2000b).

According to the biocomplexity theory (Thompson *et al*. 2001) landscape is one of the possible dimensions in which the complexity of our planet is realized. A landscape is built by energetic, informative and semiotic interactions between the different actors that appear into a specific area. Between patterns and processes operating at the resolution of human scale, heterogeneity, fragmentation, connectivity and changes in land use have been the most popular subject of recent investigation (Turner 1987, 1989).

On the side of the application of landscape principles to planning and conservation, a huge amount of contribution enrich the scientific literature (*f.i.* Gutzwiller 2002, Liu and Taylor 2002, Forman *et al*. 2003). Conversely very few attention has been paid to develop theories and new paradigms (Phillips 1999).

4. THE DEFINITION OF LANDSCAPE

Many landscape ecologists have tried to define the landscape either as a geographical entity, either as a metaphysical subject, spreading a lot of confusion and contradiction. The debate on this subject actually is apparently extinguished more for the lack of agreement that for the presence of a definitive solution.

One of the first step in developing theory for a science of landscape is to define the nature of the landscapes. Landscape is an entity with physical as well as conceptual properties (Fig. 1). Landscape is not a unitarian object but according the complexity theory we can consider at least in three ways the landscape: as a system, as a unit and as a domain. This approach collides with the practice to focusing on unique exclusive definition by using the reductionistic approach. These three interpretations have in common the space as unifying and distinct character.

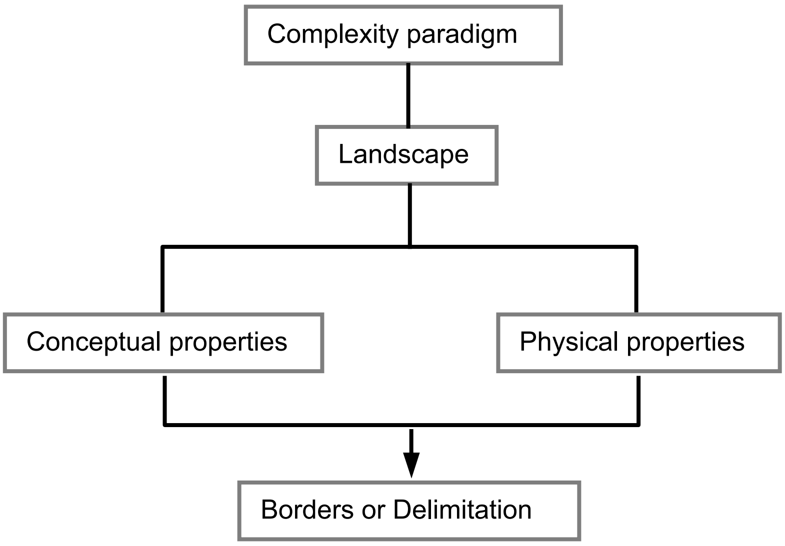

Figure 1. Moving from the complexity paradigm landscape can be considered an "entity" with conceptual and physical properties with delimitation in space and time (from Farina in prep.).

4.1 The landscape as a domain

We intend for domain the physical and conceptual dimension in which, for a specific entity, the full range of relationships and interactions are working. The domain is a process as well a patterned space. Domain is a unit of the complexity, is a close system in term of self-functioning and contemporary is an open system in terms of effects. Domain is the delimited universe in which a process happens, evolves or is maintained. Like an autopoietic machine (*sensu* Maturana and Varela 1980) a domain contains all the necessary mechanisms, tools, material and energy for the functioning of a specified entity. Domains can overlap each other and can share common elements, in this case the interaction between domains can create meta-domains. The landscape domain is considered by our theory one of the largest inside the complexity and inside this domain can be found other domains in a hierarchical framework (see Table 1 and Figure 2). The decision to organize in such a way this piece of the complexity is absolutely subjective but if this conceptual framework allows to understanding the complexity of our life (biological and spiritual), we can accept this with enthusiasm. Landscape paradigm (like the complexity) remains a paradigm not self-explaining, this is the "trick" of the complexity.

4.2 The landscape as a unit

If we assume that landscape is a unit we have to distinguish such unit from the background (Fig. 3). This assumption has been incorporated spontaneously into the

ecology of the landscape especially from the American school of landscape ecology. For instance if we select a watershed as landscape unit, this watershed must have border and distinct characters. In general is surficial water the entity by which we can distinguish such unit. On the contrary is not possible to distinguish a watershed by using vegetation. Vegetation can be used to distinguish associations or, operating at larger scale, biomes. When we consider landscape as a unit, we have to assume unitarian functioning like for organisms and to assume autopoietic character to self-organizing and self-controlling. Landscape as a unit can be considered a patch into a landscape matrix. For instance we can define the "Tuscany landscape" that we can distinguish from the Ligurian or whatsoever region and is a unit of the Italian landscape matrix. Moving up the Italian landscape is a unit of the Mediterranean landscape matrix. In conclusion the size of landscape as unit is not fixed but depends on the type for landscape considered. Again landscape unit is not self-explaining.

Table 1. The landscape domain contains several other sub-domains than can interact each other composing meta-domains. In the table we represented a small part of these domains.

A: Landscape domain
B: Physical/Cognitive realm meta-domain
C: Macro-Processes meta-domain (Economics, Policy, Religion, Culture, Environment)
D: Disciplines meta-domain (Ecology, Geology, Ethology, Planning, Medecine, Social sciences, ...)

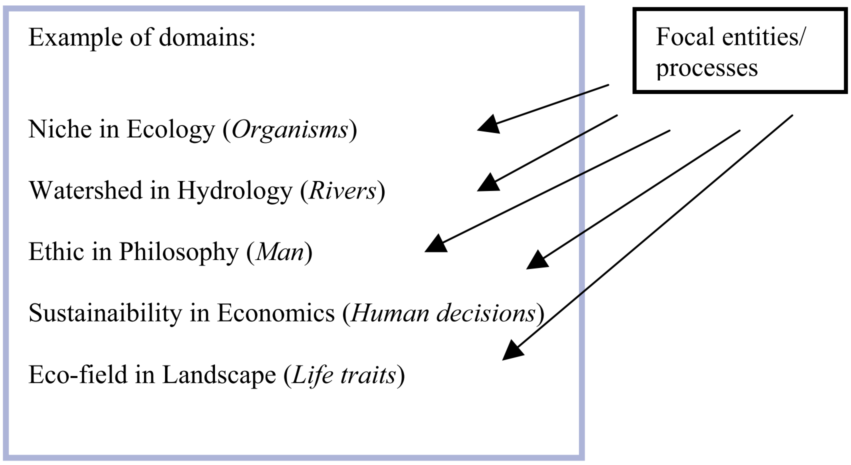

Figure 2. Some examples of domains in different field of human interest, the interactions between domains create meta-domains and contribute to the complexity.

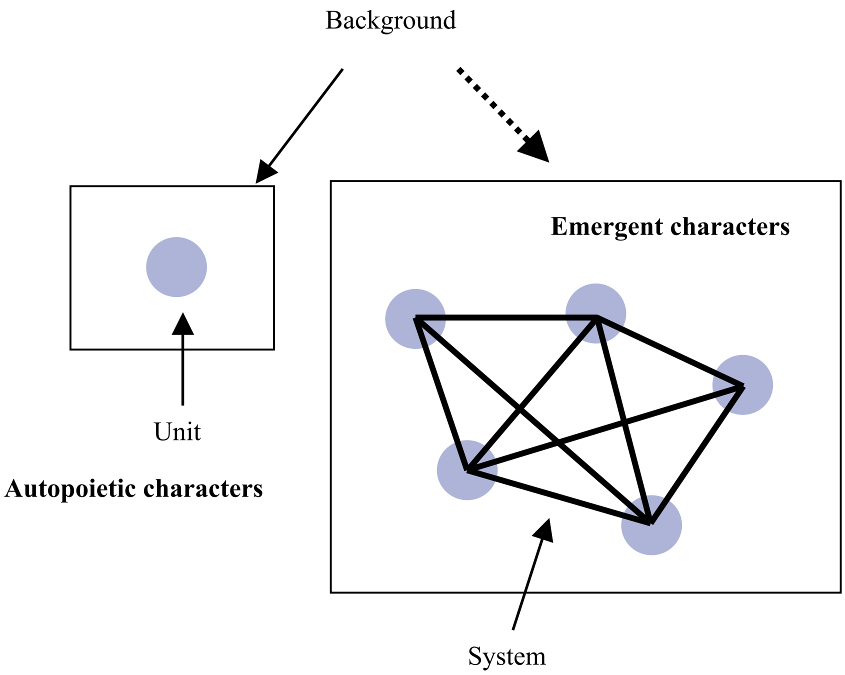

Figure 3. Landscape can be considered a unit or a system. Both the conditions are possible, but the approaches to investigate and to apply knowledge for land management are quite different (from Farina in prep.).

4.3 The landscape as a system

The landscape can be considered as system when we focus on emergent properties like fragmentation, connectivity, ecotones, etc. In many cases some confusion appears in literature. If we consider landscape like a system we must focus on the emergent patterns and processes born from the interactions between the composing parts (Fig. 3). Are not the patterns but the processes the main object of investigation. The background disappears and a mosaic of elements (patches), is considered source of the observed processes. For instance, for a bird the landscape is a system composed of patches with different quality according the function active at the moment. For a bird, landscape is a system that provides food, shelter, water, nesting and roosting places. We will discuss later this important subject in the section devoted to the individual-based landscape.

5. THE COGNITIVE LANDSCAPE

Cognition is a property of life and under this umbrella we can define the landscape according to three distinct perspectives (Fig. 4):

. Individual-based landscape (IBL)

. Observed-based landscape (OBL)

. Neutral-based landscape (NBL).

The IBL is the result of organism perception of the living landscape domain. We discuss later that IBL is the result of several eco-fields. The OBL is the result of human perception of the surrounding integrated with the human specific IBL. Most of our knowledge of the world is based on our capacity to observe more than the IBL, this probably makes the difference between man and all other organisms. But the observation outside the IBL domain that is species-specific, introduces many biases in our results compressing different domains. Most of the failures in managing complexity depends by our incapacity, during the observation, to distinguish the domains from which a pattern or a process are pertaining. Our capacity to observe is strongly enhanced but also affected by culture (written or oral).

The NBL is the landscape that exists also outside the cognition and the observation. Of course is not visible to us and contains all the objects that in turn are not perceived by organisms but that exist. For instance a spider web exists but is not visible by flies. Ultrasonic calls of bat are outside the auditory spectrum of human hear but are signals for other bats and moths. NBL can't be observed, neither perceived by cognition but we know that exists and the interactions inside a NBL can produce stochastic effects on processes or organisms. The impredictability of a complex system probably depends on the NBL, and this is an other important character of the complex systems. We will discuss later in the section devoted to landscape ontogenesis the role of the stocasticity.

6. THE ECO-FIELD MODEL TO INTERPRET THE IBL

Cognition is a common property of every living systems, from cells to colonial organisms. Cognition means the capacity of a living entity to communicate with the surrounding world. According to the theory of the meaning formulated more than 50 years ago by von Uexkull (Uexkull 1940) every organism recognizes the surrounding "Umwelt", assigning a specific meaning to selected objects that become "meaning carriers". We call eco-field the space of existence of the meaning carrier when enters into contact with the organism. For every function an organism searches for a specific function meaning carrier. For instance for a bird of prey like the kestrel (*Falco tinnunculus*) food is represented by insects, mammals and reptiles of small size. Every prey is a meaning carrier, but kestrel searches these prey in open areas (prairies, forest clearance), the eco-field is represented by such spaces that must have a particular configuration to be recognized as area for hunting. According to the theory of meaning the eco-field can be defined as a "Space Configuration Meaning Carrier". The IBL is the domain of all the eco-fields perceived by an organism.

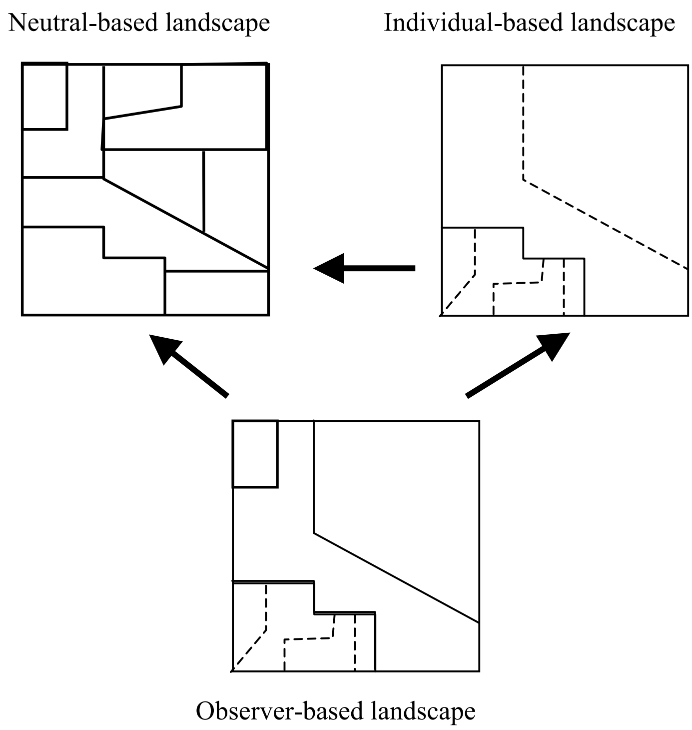

Figure 4. Relationship between the three types of cognitive landscapes.

The eco-field paradigm allows to distinguish the domain for every vital function and scoring the value of suitability. In this way it is possible to distinguish individuals inside a population according the quality of every eco-field and to predict the genetic variability expected. The eco-field is the projection of the niche into the space and is more efficient to describe the surrounding of a species than by using the habitat concept that in many cases is too vague or used in wrong way if not associated to a species. The eco-field paradigm open a new a more efficient road of investigation especially for species rare or menaced of extinction because genetic foot-print can be coupled to environmental conditions.

But when we consider a landscape like a system and we are dealing with the emergent properties the eco-field paradigm can be used as the domain of such properties. Fragility, resilience, diversity, heterogeneity are some of the properties that "emerge" from every complex system. Such properties receive from the system a score according to the processes involved and their distribution is not homogeneous. We assume that the unequal appearance of such emergencies can be traced into a space (the eco-field). Assuming, for example, that an entity like a forest has emergent properties that determine the state and the future of the forest.

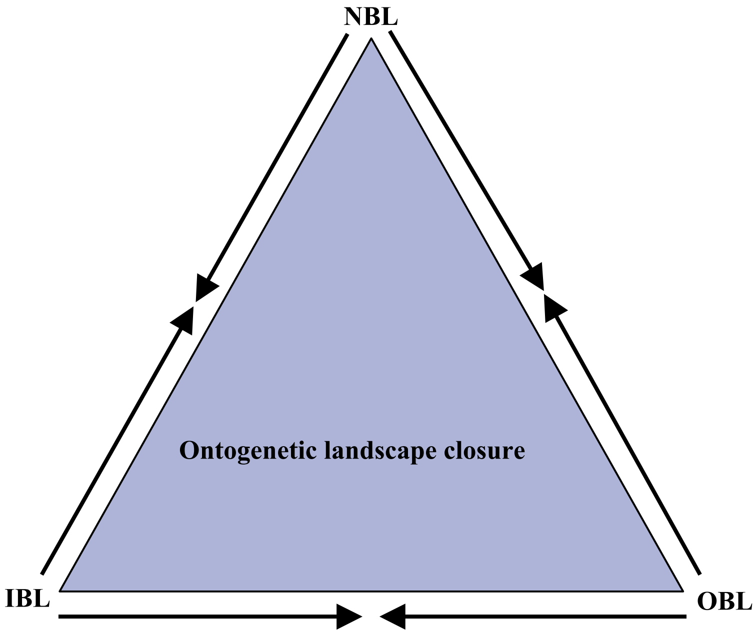

Figure 5. Landscape ontogenesis.

7. LANDSCAPE ONTOGENESIS

Most of the knowledge on the landscape are based on the studies of dynamics. For instance how land use changes inside a temporal window, how the land mosaic is affected by changes in economics, etc. No attention is paid to describe the formation of a landscape because our science is based on the cause-effect relationship. We have described in the past session how landscape is structured and according the different perspectives we can expect an evolution different according to the selected view. This is absolutely correct, IBL, OBL and NBL concur separately to the ontogenesis of the landscape under the pressure of many different forces (mostly not teleonomics). It is evident that there are not possibilities to rank the three perspective in order to explain the landscape ontogenesis (Fig. 5). These three components of the complexity create a landscape ontogenetic closure. Landscape ontogenesis is the result of this circle.

When an event occurs without a clear relationship cause-effect we consider this event stochastic. Stochasticity is one fundamental property of the complex systems, is the alternative to the wheel-gear world, the soap bubble world.

We can know what will happen when energy, information, signals, memory and cognition blend together by the interaction inside domains and between meta-domain. We can know only a part of the story if we selected a small piece of the

complexity like an individual organism or a cell. If we observe magnitude and frequency of the processes its possible to recognize at least three main processes common to every landscape that we call simply: opportunities, events and novelties.

Opportunities represent the most common and frequent occurrence inside the selected system. The coalensce of species inside a community is an example of opportunity. The energy necessary to carry out this process is extracted by the elements composing the system. Events represent the exchange of energy, material and information between the neighboring systems. Are less frequent that opportunities and the energy is produced by the energetic gradient existing between the systems. Events are the main responsible of ecotone effect.

Finally novelties are changes of spatial and functional configuration of the mosaics. Novelties require energy from outside the system and their occurrence is infrequent. Extreme flooding, tornado of great intensity, earthquake of high magnitude are some of the phenomena that can produce a dramatic change into the configuration of a landscape.

8. REFERENCES

Farina, A. 2000a. *Landscape ecology in action*. Kluwer Academic Publishers, The Netherlands.

Farina, A. 2000b. *Principles and methods in landscape ecology.* Kluwer Academic Publishers, The Netherlands.

Farina, A. 2003. Focus on ecological complexity of aquatic systems: theory and application for a (ethic) sustainable management. *Proceedings of the International Trade Fair on Material & Energy Recovery and Sustainable Development.* Rimini (in press)

Farina, A. (in prep). The landscape web: at the dawn of a new science.

Forman, R.T.T. and M. Godron 1986. *Landscape ecology*. Wiley & Sons, New York.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T. and Winter, T.C. 2003. *Road ecology. Science and Solutions*. Island Press, Washington D.C.

Gutzwiller, K.J. 2002. *Applying landscape ecology in biological conservation.* Springer, New York.

Haber, W. 2002. Ethics and morality in the sciences. Proceedings of 8th INTECOL International Congress of Ecology, Seoul, Korea.

Holling, C.S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. In W.C. Clark and R.E. Munn (Eds.). *Sustainable development of the biosphere* (pp. 292-317). IISA, Cambridge University Press, MA.

Kuhn, T.S. 1962. *The structure of the scientific revolution*. The University of Chicago Press, Chicago.

Lawton, J. 2001. Earth System Science. *Science* 292: 1965.

Liu, J. and Taylor, W.W. 2002. *Integrating landscape ecology into natural resource management*. Cambridge University Press, Cambridge.

Maturana H.R. and Varela, F.J. 1980. *Autopoieisis and Cognition: The Realization of the Living*. Reidel, Dordrecht.

Muller, F. 1997. State-of-the-art in ecosystem theory. *Ecological Modelling* 100: 135-161.

Naveh, Z. and Lieberman, A. 1984. *Landscape ecology*. Springer-Verlag, New York.

Odum, H.T. 1983. *System ecology: An introduction*. Wiley & Sons, New York.

O'Neill, R.V. 2001. Is it time to bury the ecosystem concept? (with full military honors, of course!). *Ecology* 82: 3275-3284.

Phillips, J.D. 1999. Divergence, convergence, and self-organization in landscapes. *Annales of the Association of American Geographers* 89: 466-488.

Tilman D.R., May, M., Lehman, C.L. and Novak, M.A. 1994. Habitat destruction and the extinction debt. *Nature* 371: 65-66.

Thompson J.N., Reichman, O.J., Morin, P.J., Polis, G.A., Power, M.E., Sterner, R.W., Couch, C.A., Gough, L., Holt, R., Hooper, D.U., Keesing, F., Lovell, C.R., Milne, B.T., Moles, M.C., Roberts, D.W. and Strauss, S.Y. 2001. Frontiers of ecology. *Bioscience* 51: 15-24.

Turner, M.G. 1987. *Landscape heterogeneity and disturbance*. Springer-Verlag, New York.

Turner, M.G. 1989. Landscape ecology: the effect of pattern on process. *Annu. Rev. Ecol*. Syst. 20:171,197.

Turner, M.G., Gardner, R.H. and O'Neill, R.V. 2001. *Landscape ecology in theory and practice. Pattern and process.* Springer-Verlag, New York.

von Uexkull, J. 1940. *Bedeutungslehre*. Barth, Leipzig.

Wiens, J.A. 1995. Landscape mosaics and ecological theory. In L. Hansson, L. Fahrig and G. Merriam (eds.). *Mosaic landscapes and ecological processes* (pp. 43-62). Chapman & Hall, London.

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TOSHIYUKI NAMBA & TAE-SOO CHON

CHAPTER 2

MATHEMATICAL VIEW OF COMMUNITY AND ECOSYSTEM PROCESSES

1. INTRODUCTION

One of the basic questions in ecology is to understand how the ecological communities and ecosystems are organized. It has gained the greater importance because of the growing concern about the conservation of biodiversity and restoration of damaged ecosystems in a changing world. Species interactions and spatio-temporal variability are the key factors influencing ecological processes. Since many problems interconnect across a range of spatial and temporal scales in the natural world (Levin 1992, Maurer 1999), mathematical modelling is one of the fundamental approaches for untangling the complex networks of interactions in a spatially heterogeneous and temporally varying world. Marked advances in community and ecosystem ecology will be achieved by coordinated development of manipulative experiments on community-wide scales and insightful theoretical investigations.

The 8th International Congress of Ecology (INTECOL) was held in Seoul with “Ecology in a Changing World” as the main theme. The symposium “Mathematical View of Community and Ecosystem Processes” was organized to review recent progresses in mathematical theories in community and ecosystem ecology. Our attention was particularly paid to the following aspects; empirical models stemmed from observations of aquatic communities; spatial models for explaining mechanisms which promote coexistence of multiple species; models to access ecosystem health and performance focusing on the matter and energy flow; a model to evaluate efforts to conserve populations; and an evolutionary model for describing self-developing processes of food webs.

In this article, we summarize the lectures in the symposium and give a brief review of the background and status of the mathematical view in community and ecosystem ecology. Lawton (2000) wrote that four inter-related challenges confronting community ecology in a rapidly changing world would shape up to this millennium. These are (1) whole system manipulations simulating aspects of global change, (2) approaches in some ways to regional processes, (3) greater collaboration of community ecology and ecosystem ecology, and (4) works with laboratory

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microcosms and controlled environmental facilities, together with mathematical modelling. This seems a common view to ours, although more mathematical viewpoints were emphasized in our symposium. In the following, we concentrate, first on spatial aspects including regional processes, second on long-term temporal issues, and third on ecosystems and physical processes. Finally we will suggest some future directions that have become clear through recent development in this field and discussions in the symposium.

2. SPATIAL HETEROGENEITY AND COMMUNITY DYNAMICS

Spatial and temporal heterogeneity in habitats is essential in structuring ecological communities. Thus, it is important to ask questions in spatio-temporal contexts in community ecology. Larger-scale processes occurring at longer temporal and larger spatial scales may modify the outcomes of many local processes regularly studied by community ecologists (Ricklefs 1987). Therefore, we need to expand a range of spatial and temporal scales to understand community dynamics (Ricklefs 1987, Brown and Maurer 1989). Even if spatial and temporal patterns in environmental factors can be elucidated, it is not easy to empirically evaluate their effects on dynamics of complex communities. Therefore, it is one of the important theoretical challenges to reveal the consequences of spatial and temporal heterogeneity on the community dynamics, in addition to effectively extracting information on environmental factors and expressing ecosystems in an integrated manner, which will be discussed later.

Spatial models have recently been studied extensively (Hanski and Gilpiin 1997, Tilman and Kareiva 1997). In the midst of the last century, Skellam (1951) first applied the analytical expression of molecular diffusion to ecological problems for investigating coupled effects of dispersal and growth of a single population (Okubo 1980). An extension of the method into a collection of interacting populations has led to flourishing of so-called reaction-diffusion models (Okubo and Levin 2001). They also include models describing a situation where populations are distributed patchily and space is treated as a discrete entity (Levin 1974, Levin and Pacala 1997). Spatially discrete reaction-diffusion models can explicitly incorporate both a spatial configuration of discrete patches and within-patch population dynamics (Namba *et al* 1999). Although the reaction-diffusion models have been successful in explaining propagation of populations and spatial pattern formation, they have some limitations and a variety of other spatial models have been proposed, for example, patch-occupancy models, cellular automata, individual-based models, coupled map lattice models, interacting particle models, and so on (Tilman and Kareiva 1997).

These spatial models are often called metapopulation models collectively. In a narrow sense, a metapopulation model denotes the Levins's (1969) classical model that deals with the fraction of occupied sites in a patchy habitat divided into distinct sites. From a slightly different standpoint, a metapopulation model was developed to describe the dynamics of marine invertebrates with a life cycle including planktonic larvae and sessile adults (Roughgarden and Iwasa 1986, Iwasa and Roughgarden 1986). The metapopulation consists of many space-limited local habitats for sessile

adults which supply planktonic larvae into a common regional larval pool. The larvae in turn settle on vacant space in the rate proportional to the amount of free space in the local habitat. Roughgarden and Iwasa (1986) and Iwasa and Roughgarden (1986) proposed models of differential equations describing the numbers of adults in local habitats and the abundance of larvae. Similarly, the lottery competition model for space (Chesson and Warner 1981) assumed that a randomly chosen dispersing larva of each species in a common pool could fill a vacant site in a habitat when an adult occupying the site died. However, in the standard lottery model, space was not explicitly introduced and only the proportions of sites occupied were considered.

In "Lottery competition: a mechanism of species coexistence" Muko and Iwasa spatially extended the lottery competition model (Chesson and Warner 1981) by incorporating many different local habitats and revealed the importance of permanent spatial heterogeneity for coexistence of competitors (Muko and Iwasa 2000). The lottery competition was often invoked as a mechanism for coexistence of competitors maintained by temporal fluctuations of environments (Chesson and Warner 1981). Muko and Iwasa introduced between-habitat variation, instead of temporal fluctuations, in mortality and reproductive rates into the lottery competition model. Their main conclusion was that heterogeneity in mortality rates did, but heterogeneity in reproductive rates did not, promote coexistence, which sharply contrasted with the condition for species coexistence due to year-to-year variations in the usual lottery model (Chesson and Warner 1981). They also found that, if the larval dispersal between habitats was limited and complete mixing was not the case, spatial heterogeneity could promote coexistence in a considerably higher proportion than temporal fluctuations did.

One of the several drawbacks of diffusion models may be that they imply infinite speeds of propagation. Thus, they may prevent the transient isolation that often is essential to persistence of competitively inferior species (Levin and Pacala 1997). In "Community dynamics in a heterogeneous landscape" Namba examined the effects of dispersal and spatial heterogeneity for indirectly interacting populations. Two consumers feeding on a common resource compete exploitatively through depletion of the shared resource. Two prey species sharing a common predator also compete apparently because an increase in either prey augments the predator and hence the predation pressure on the other (Holt 1977). Namba *et al.* (1999) found that diffusive dispersal of predators could promote coexistence of apparent competitors in source-sink habitats, and that the spatial configuration of a source and sinks might greatly influence persistence of regional communities. In his presentation, Namba assumed random dispersal of populations between two different habitats and found that diffusion could mediate regional coexistence of two exploitatively or apparently competing species, even though an inferior competitor definitely went to extinction in both habitats if they were isolated. The mechanism to promote coexistence was not the usual competition-colonization trade-off and the higher dispersal rate of the superior competitor could facilitate coexistence.

3. EVOLUTION OF COMMUNITIES AND CONSERVATION ISSUES

Temporal heterogeneity also has profound effects on community structure and dynamics. The application of differential equation models to population dynamics originating in the early 1920s led to initial development of the equilibrium theory mainly focused on the role of competition structuring communities (Cody and Diamond 1975). However, in the late 1970s, prevalence of density dependent regulation and interspecific competition in the natural world was questioned and the necessity of nonequilibrium theory describing communities in variable environments was emphasized (Strong *et al*. 1984, Diamond and Case 1986). Hutchinson (1961) noticed the importance of environmental fluctuations as a mechanism to explain coexistence of many planktonic populations competing for similar resources in relatively homogeneous aquatic environments. As explained earlier, year-to-year stochastic variations in some demographic parameters could promote coexistence of lottery competitors that could not co-occur in a constant environment (Chesson and Warner 1981). Namba (1984) and Namba and Takahashi (1993) investigated the Lotka-Volterra's competition equations with periodically varying coefficients and showed that seasonal environmental fluctuations could enhance coexistence of competing populations. They also suggested that the community structure might highly depend on the history of the community in a seasonal environment since the appearance of multiple alternative stable states would make it contingent on the population abundances and the timings at the invasion events.

Species abundances and composition in local communities drift over time (Lawton 2000). Local biodiversity is influenced by patterns on regional scales. Diversity in geographic assemblages of species is determined by processes on geological time scales (Maurer 1999). Thus, patterns of accumulation of diversity over time should ultimately be regulated by speciation and extinction of species (Rosenzweig 1995, Maurer 1999). We can construct a model of evolution of diversity by differential proliferation of species, linking population dynamics with changes in the number of species in an evolving clade over time (Maurer 1999). In "Evolutionary dynamics of self-developing food-web," Ito and Ikegami assumed that new species were generated through recursive speciation and developed a model of evolutionary branching caused by predatory interactions between species characterized by two traits, r as a resource and u as a utilizer (Ito and Ikegami 2002). They considered a phenotypic space of r and u and computed the gain and loss per individual of each phenotype from the resource flow. Defining a trophic species (Cohen *et al*. 1990) as an isolated phenotype cluster, they showed that a complex food web could develop from a single species through recursive branching and extinction. They also found divergence through evolutionary branching at a shorter time scale and repeated mass extinction and recovery at a longer evolutionary time scale. Other insights were the higher species richness at the intermediate interaction strength and a convex relationship between the number of trophic species and biomass. Some assumptions in their model, including the dimension of a trait space, might be refined in the future.

Since the recent global change by human activities have devastated natural ecosystems and huge numbers of species have declined rapidly, it is an urgent need

to save natural populations from extinction and conserve biodiversity (Lubchenco *et al*. 1991). A natural population often fluctuates temporally, which may be caused by climatic variation becoming more and more unpredictable by the global change (Lawton 2000). In "Optimal conservation effort for a population in a stochastic environment," Yokomizo *et al*. reported on the optimal conservation effort for a population in a fluctuating environment. The higher conservation effort improves survivorship but accompanies the higher cost. The total cost can be defined as the weighted sum of the population extinction risk and the economic cost of conservation effort. Since the extinction risk decreases and the economic cost increases with increasing conservation effort, there should be some optimum conservation effort that minimizes the total cost. Since the larger variance in the environmental noise increases the extinction probability, the conservation effort is not effective in reducing the extinction risk without investing costly effort when the variance is very large. Thus, as shown by Yokomizo *et al*., the optimal conservation effort is small both for very small and very large variance. They found that the conservation level for the multiple-year optimization became lower than that for the single-year optimization if the population was endangered since investing less effort to conservation increased the extinction risk but eliminated the future total cost. They also discussed the effects of the economic discounting for future investment and the research effort to estimate uncertain parameters. In a fragmented landscape, spatial structure may also be important to assess the extinction risk. In making difficult choices about where and what we try to save, it may also be important to consider the amount of independent evolutionary history we save for future generations (Nee and May 1997).

4. ECOSYSTEM DYNAMCS AND PSYSICAL PROCESSES

Spatial and temporal heterogeneity embedded in environmental factors express ecosystems' structure and function uniquely in nature. Environmental factors, being linked with biological organisms in a complex manner, in turn, collectively establish characteristic patterns across different scales in spatial and temporal domain (*e.g*., Allen and Starr 1982, Minshall 1983, Levin 1992). Methodology for objectively quantifying ecosystem characteristics has been one of the key issues in contemporary ecology. For the practical side of ecology, characterization of ecosystem quality deserves full attention in revealing complex environment-community relationships regarding conservation of natural resources or sustainable ecosystem management. However, not much study has been carried out from the theoretical aspect. Due to non-linearity resided in ecosystem data, it has been difficult to develop methods for evaluating ecosystems objectively and efficiently; both communities and environment consist of multi-variables fluctuating in a great degree, reflecting numerous impacts of endogenous and exogenous agents. The issues are how information is effectively extracted from the complex data without loosing original integrity, and how ecosystems are expressed in an integrated manner to be comprehensible to humans. Two approaches were discussed in the Seoul INTECOL in this regard. Firstly, implementation of the methods in machine

learning was investigated to efficiently extract information from ecosystem data, and secondly expression of integrative characterization of ecosystems was discussed in the context of physical processes.

Recently information-extraction methods in machine intelligence including artificial neural networks (ANN) have drawn a strong attention as an alternative tool for predicting and interpreting complex data in ecology (Lek and Guegan 2000, Recknagel 2003). Since a neural computation system was proposed by McCulloch and Pitts (1943) in the forties in the 20th century, ANN and other adaptive computational methods have been widely implemented in interpreting complex and nonlinear phenomena, especially since eighties in the last century. Artificial neural networks consist of distributed information extraction processors working in parallel, have adaptive and self-organizing properties, and are consequently feasible in handling complex and nonlinear data (see Rumelhart and McClelland 1986, Lippmann 1987, Zurada 1992, Haykin 1994). The processes in learning in artificial neural networks are in fact mostly based on physical processes: computational algorithms are conducted in accordance with thermodynamic principles, consequently finding global minima through exploration of simulated annealing, Boltzman machine, etc (*e.g.*, Hopfield 1982, Kirkpatrick *et al.* 1983, Hinton and Sejnowski 1986, Oh *et al.* 1995). In ANN, the model does not generally find the answer directly. Through adaptive learning mechanisms, the systems gradually settle down to the global minima as the most probable state through stochastic processes.

In the topic of "Patterning on community organization through learning process: implementation of artificial neural networks on benthic macro-invertebrates in streams" in the Seoul INTECOL presentation, Chon *et al.* demonstrated ANN as an efficient tool to reveal complex relationships among variables in community and environment. Classification and ordination in multivariate data were efficiently carried out with the use of the self-organizing mapping (Kohonen 1982, 1984, Chon *et al.* 1996, 2000b). The multi-layer perceptron was utilized to manifest the causality lied between environmental factors and communities in numerous accounts, including habitat suitability for fish (*e.g.*, Lek *et al.* 1996), prediction of algal community abundance (*e.g.*, Scardi 1996, Recknagel 1997), etc. Community dynamics in time series data was predicted by implementing the recurrent networks (Chon *et al.* 2000a, 2001). With flexibility in the networks' architecture, the development of hybrid-type networks was further discussed to reveal complex patterns in community and ecosystem dynamics.

Additionally, integrative parameterization of ecological data has been a critical issue in characterizing establishment of ecosystems. Self-organization processes in ecosystems have been scrutinized, and various goal functions and related concepts in revealing ecosystem property have been proposed in the context of physical processes (Odum 1983, Jørgensen 1998). Especially, maximum power was among the key concepts to explain continuous establishment of ecosystems. Through self-organization, systems develop to maximize power to reinforce energy production and efficiency, consequently achieving continuous maturity in ecosystems (Lotka 1922, Odum and Pinkerton 1955, Odum 1983). Additionally, the adaptive processes in ecosystem establishment were interpreted through various energy-related

concepts such as minimum entropy (Glansdorff and Prigogine 1971), maximum biomass (Margalef 1968, Straskraba 1979), maximum ascendency (Ulanowicz 1980), etc.

Especially the concepts of "exergy" and "emergy" are notable in revealing the status of information accumulation in ecosystems. Embodied energy/emergy (Odum 1983) has been one of the well known "ecological energy units" to express ecosystem quality: it measures the total energy embedded in the organisms in hierarchical organization in ecosystems with different energy conversion coefficients. The biomass at the higher levels of food chain, for example, requires higher amount of emergy than that required by the same amount of biomass at the lower level. While emergy basically indicates ecosystem quality through solar-energy conversion via energy flow, exergy has been coined to reveal an evolutionary property of a system, i.e., the level of organization or the information content in ecosystems (Mejer and Jørgensen 1979, Salomonsen 1992).

Exergy reveals the maximum work that can be extracted from a system towards the thermodynamic equilibrium with a reference state. A relative exergy could be further calculated by summation of biomass of the selected taxa multiplied by weight values representing information stored in the selected taxa (Salomonsen 1992). Specific exergy (*SE*; structural exergy) could be additionally defined as the exergy divided by total biomass. The specific exergy measures the ability of the ecosystem to utilize the available resources. When an ecosystem has the higher specific exergy for instance, it follows a thermodynamic path that will bring a higher organizational level through natural selection (Jørgensen, 1995a, 1995b, Bastianoni and Marchettini 1997).

In "Exergy and emergy as ecosystem health indicators of Nakdong River, South Korea" Kim and Jørgensen utilized exergy and other related concepts such as emergy/exergy ratio, and subsequently characterized the eutrophic states of river ecosystems. They reported that exergy ratio of phytoplankton to zooplankton was a good indicator of balance, while specific exergy efficiently revealed organization level and structure of ecosystems. Emergy/exergy and emergy/SE ratios can be used as reliable ecological indicators of ecosystem efficiency and organization level of plankton communities in the river systems.

In "Pulsing cycles for maximum power" Kang focused on pulsing patterns in relationships with maximum power principle. Kang reported that self-organization in ecosystems increases performances by accumulating storages. The storages are in turn transferred to a higher consumer level in the energy hierarchy, and subsequently fed back in sharp repeating pulses. Consequently, systems that pulse may prevail by drawing in and transforming more power than systems that do not (Kang 1998).

Kang analysed various field data and reported that pulse amplitude was proportional to the time interval between pulses of similar size. Small-scale pulses were more frequent, while large-scale pulses delivered their effects in shorter time periods relative to their intervals. Whereas the model with a single pulsing pair unit did not generate pulsing patterns when energy input was very low or very high, compound design allowed excess input energy to be routed to the productivity of other pulsing units. He observed various patterns supporting the theory of pulsing paradigm, and further showed that the pulsing producer-consumer unit drew more

power than a non-pulsing producer-consumer unit with similar calibrations. Kang demonstrated that in systems management, performance may be increased by adapting uses to the pulsing regimes rather than by trying to develop steady states.

5. FUTURE DIRECTIONS

As well documented, ecosystems and communities are characterized by unique attributes in their organizations; complex inter-relational ecological phenomena (e.g., food chain/web, biogeochemical cycle, etc) are tightly fabricated on the non-linear, multi-variate framework of ecosystems. The concepts of hierarchy and network have been proposed to accommodate these complex structural and dynamical frameworks of ecosystems. In organizational perspective in ecosystems, the stability-related problems in multivariate dynamics have been key issues and would be still listed on top for the future study in ecosystem dynamics.

Communities and ecosystems are so complex and often unstable because of the nonlinearity of interactions between the components. In his seminal work, May (1972, 1974b) investigated properties of random community matrices and demonstrated that stability tended to decrease with complexity. May's classical question on the relation between 'complexity and stability' (May 1974b) is still one of the contemporary problems (May 2001) known as the relation between 'diversity and stability' (McCann 2000) and has been actively investigated (see for example, Chawanaya and Tokita 2002, Jansen and Kokkoris 2003).

Nonlinear interactions not only destabilize equilibrium but sometimes give rise to astonishingly complicated dynamics including stable cycles, and chaotic fluctuations that are apparently indistinguishable from random variations and sensitively dependent on initial conditions (Hastings *et al.* 1993). It is well known that chaos appears in simple discrete population projection maps such as the logistic or the Ricker map (May 1974a) and in continuous dynamical models of three interacting populations (Vance 1978, Gilpin 1979, Hastings and Powell 1991). Nonequilibrial oscillations caused by nonlinear interactions are sometimes essential for coexistence of competing populations (Hsu *et al.* 1978, Armstrong and McGehee 1980) and assemblages of three or more populations competing for essential resources may exhibit chaos (Huisman and Weissing 1999). However, among empirical ecologists, the view that chaos is unimportant in natural populations seems prevailing (Hastings *et al.* 1993). Recently, on the contrary, laboratory populations of cannibalistic flour beetles could demonstrate chaotic oscillations (Cushing *et al.* 2002). A large number of controlled experiments and further development of techniques (Perry *et al.* 2000) may be required in order to disclose the degree of generality of chaos in time series data obtained empirically. Since we have not yet revealed the whole range of dynamics of ecological communities, exploration of nonlinear dynamics is still an important issue in this century, while, at the same time, the other line of premise that communities and ecosystems can obey simple rules even if constituent populations exhibit complex dynamics (May 1999) could be also scrutinized in the future.

Complex networks of interactions characterize ecological communities and the network configuration or the topological structure of food webs is important in determining community dynamics (Pimm 1982, Lawton 1989, Cohen *et al.* 1990). However, elaborate studies of food webs in the last decade of the 20th century (Winemiller 1990, Martinez 1991, Polis 1991) discouraged the premise that we could have found the basic rules that govern the food web architecture (Pimm *et al.* 1991, Hall and Raffaelli 1993, 1997). Prevalence of omnivory that has been considered rare (Pimm 1982) forces rethinking of community structure. Propagation of several kinds of indirect effects (Wootton 1994, Menge 1995) through webs of interacting species plays an important role in determining local community membership but makes the discovery of causal relationships more difficult (Yodzis 1988, Maurer 1999, Lawton 2000). Thus, even a simple attribute of food webs such as the length of food chains has not been satisfactorily resolved (Post 2002). The quest for food web patterns remains a central question for ecological sciences (May 1999) and mathematical models should play a key role to find them.

Hierarchical perspectives are also indispensable to understand the structure and dynamics of communities and ecosystems. Interactions between local populations influence the number of species and dynamical processes in communities that are also controlled by physical processes operating in the ecosystems in which the communities are embedded. This makes the theories of community ecology contingent upon the organisms involved and on their environment (Lawton 2000). Communities and ecosystems also exist in a hierarchical context across a range of spatial and temporal scales (Levin 1992). Local communities assemble themselves from a regional pool of species through a series of filters working on different spatial and temporal scales (Lawton 2000). Larger-scale processes occurring at longer temporal and larger spatial scales may modify the outcomes of many processes in local communities (Ricklefs 1987, Brown and Maurer 1989). Variability and complexity in a system with a large number of components tend to cause indeterminacy (Maurer 1999) and small changes in initial conditions may lead to divergent end results as the system changes over time (Hastings *et al.* 1993). In hierarchically organized systems, regularities in the focal level are often determined in a statistical sense by the components or the objects in the next lower level and these are in turn constrained by their interactions with other objects in the same level and external conditions forced upon them by processes occurring at higher levels (Maurer 1999). Thus, for discovering regularities and generalities in ecological systems, it may be crucial to seek macroscopic or statistical patterns at appropriately large spatial and temporal scales (Maurer 1999).

This large-scale perspective termed macroecology (Brown and Maurer 1989, Brown 1995) has focused mainly on a variety of correlations among distributions of local abundances of species, local and regional species richness, species geographic ranges, and body sizes (Brown 1995, Gaston and Blackburn 2000). A broad statistically significant positive correlation between average local population abundances of species and sizes of their geographic ranges is one of the pronounced patterns in macroecology (Brown 1995, Gaston and Blackburn 2000). Several mechanisms generating this correlation were presented (Gaston *et al.* 1997, Lawton 2000). However, none of the mechanisms including the hypotheses based on the

niche breadths and metapopulation dynamics had unequivocal and universal support. Thus, the importance of working out the relative contributions of each of the most plausible mechanisms was suggested (Gaston *et al*. 1997). If the higher dispersal rates of the superior local competitors are the key to coexistence of many species as suggested by Namba in the symposium, then positive correlations between local abundances and species geographic range sizes may result. Spatial models integrating local interactions and range expansions in heterogeneous landscapes may be necessary to fix the problem.

It is undoubtedly important to extend spatial and temporal scales and consider the interplay between local and regional processes (Levin 1992, Lawton 2000). However, in macroecological perspectives, the role of reductionists' view and mechanistic explanation tends to be [devalued] downgraded, since the extended scale makes the controlled experiment less rigorous (Maurer 1999, Lawton 2000). To the extreme, Lawton (1999, 2000) recommended that community ecologists should become macroecologists. However, whole system manipulations and works with laboratory microcosms and controlled environmental model systems (Lawton 2000) will remain useful approaches together with mathematical modelling. Davis *et al.* (1998) used laboratory microcosms consisting of sets of linked incubators simulating a climatic gradient and induced range shifts by raising temperature (Lawton 2000). Such kinds of experiments with a metapopulation structure that explicitly incorporated an environmental cline would be important to experimentally uncover the effects of spatial heterogeneity.

Metapopulation models have revealed that regional persistence of species through the spatial coupling of local populations via dispersal is possible (Hanski and Gilpin 1997, Tilman and Kareiva 1997). Similarly, a metacommunity which is a set of local communities connected by dispersal can permit regional coexistence of species (Holt 1993, 1997, Namba *et al.* 1999). As shown in this symposium, permanent environmental heterogeneity can make the metacommunity dynamics very different from self-organized spatial patterns within a homogeneous environment. Thus, to study the effect of spatial configuration of different habitats (Namba *et al.* 1999) may remain one of the important future problems.

In expanded spatial contexts including the scales from the landscape to the region (Ricklefs and Schluter 1993, Loreau *et al.* 2003), we need to consider not only the dispersal of organisms but also the spatial flows of energy and materials (Loreau *et al.* 2003). Movements of inorganic nutrients, detritus, and living organisms among habitats are ubiquitous in spatially heterogeneous landscapes and allochothonous inputs subsidize the recipient ecosystems and strongly influence the community dynamics (Polis *et al.* 1997). Although previous study was inclined to focus on subsidies in the target ecosystem, material flows are not necessarily completely asymmetrical and a subsidy should have an impact on the source from which it is drawn (Loreau *et al.* 2003). Therefore, it might be necessary to extend the perspectives of spatial heterogeneity in ecosystems and landscapes. A 'meta-ecosystem' as a set of ecosystems connected by spatial flows of energy, nutrients, and organisms across ecosystem boundaries is suggested as a possible extension (Loreau *et al.* 2003).

One of the main issues in the Seoul INTECOL was integrating community and ecosystem ecology. In this direction, research on the relation between 'biodiversity and ecosystem functioning' has been rapidly expanding with vigorous controversy over the interpretation of experiments and the mechanisms generating patterns (Schulze and Mooney 1993, Loreau *et al.* 2001, 2002b, Kinzig *et al.* 2002). This field is closely related to and a part of the field may be regarded as a descendant of the research on the relation between 'complexity and stability' (Loreau *et al.* 2002a). One of the main predictions of such studies was the positive correlation between diversity and productivity (Naeem *et al.* 1994, Tilman *et al.* 1996). However, these studies were mostly done on grasslands for a single trophic level (Aoki 2003). Therefore, researches on the relation between diversity and ecosystem functioning that include multi-trophic interactions in a variety of ecosystems are needed (Raffaelli *et al.* 2002, Aoki 2003). Particularly, in multi-trophic studies, it is crucial to determine how to measure diversity, productivity and stability for relating diversity to ecosystem functioning (Aoki and Mizushima 2001, Aoki 2003). Adequate choice of indices having unequivocal ecological and physical bases seems essential and physical views may be necessary to select and estimate these indices.

Regarding physical processes in ecosystem establishment, further research could be provisioned on how information should be efficiently and objectively extracted from the non-linear, multi-variate ecological data in spatial and temporal domain. In this perspective, complex phenomena (Patten and Jørgensen 1995) would still draw continuing attention for future investigation in ecology. For the practical side, this type of ecosystem knowledge is keenly needed for evaluating the degree of disturbance and for designing recovery processes from the stresses affecting ecosystems. For instance, freshwater ecosystems have been seriously faced with disturbance due to the "double-edged" problem, water shortage and pollution. Information extraction from the disturbed ecosystems could be an indispensable process for efficiently evaluating the stress impacts and for setting up policies for management of ecosystems. Nowadays, water quality maintenance is not only a regional or "with-in nation" problem, but is a key issue challenging globally to the world. Hence more in-depth, objective evaluation methods are urgently needed on the global basis.

Methods for expressing integrative parameters to represent ecosystem quality deserve to draw more continuing attention in the 21st century. As mentioned before topics such as maximum power, maximum entropy, maximum biomass, ascendancy, emery and exergy have been the step stone studies in this field (Odum 1983, Jørgensen *et al.* 2000). Especially, considering that organic matter is organizational outcome of ecosystem maturity and that a major source of anthropogenic stress is organic matter (*e.g.,* eutrophication), the measurement method relevant to organic matter such as maximum persistent organic matter (Whittaker and Woodwell 1971) needs to be recalled for further evaluation of regressive/progressive succession of ecosystems affected with pollution. Additionally, evaluation of optimal profits for economic systems in ecological perspectives (*e.g.*, Odum 1983, Jørgensen 1998) is another issue which humans should seriously and continuously pursue in the 21st century.

In order to more specifically judge the safe and stable states of ecosystems, the methods for measuring safety or ecosystem health have been an important topic in the applied side. Pioneering works have been conducted on ecosystem integrity (Kay and Schneider 1992), clinical ecology (Rapport 1995) and ecosystem health index (Costanza 1992). For instance, Costanza (1992) expressed the ecosystem health as the product terms of the system vigour, the system organization index, and the resilience index.

Being faced with the serious problems of environmental instability in ecosystems at one side and with the difficulty of interpreting complex phenomena in ecology at the other side, theoretical research would be indispensable as a reliable tool to interpret and solve the problems newly brought up to humans in this century: diagnostics of stressed ecosystems, estimation of recovering processes, design of environmental management strategy, judgement of ecosystem maturity, and pursuit of origin/evolution of community and ecosystems.

6. REFERENCES

Allen, T.F.H. and Starr, T.B. 1982. *Hierarchy: Perspectives for Ecological Complexity. Chicago*. The University of Chicago Press. USA. pp. 310.

Aoki, I. 2003. Diversity-productivity-stability relationship in freshwater ecosystems: whole-systemic view of all trophic levels. *Ecol. Res*. 18: 397-404.

Aoki, I. and Mizushima, T. 2001. Biomass diversity and stability of food webs in aquatic ecosystems. *Ecol. Res*. 16: 65-71.

Armstrong, R.A and McGehee, R. 1980. Competitive exclusion. *Am. Nat*. 115: 151-170.

Bastianoni, S. and Marchettini, N. 1997. Emergy/exergy ratio as a measure of the level of organization of systems. *Ecol. Model*. 99: 33-40.

Brown, J.H. 1995. *Macroecology*. University of Chicago Press, Chicago.

Brown, J.H. and Maurer, B.A. 1989. Macroecology: the division of food and space among species on continents. *Science* 243: 1145-1150.

Chawanya, T. and Tokita, K. 2002. Large-dimensional replicator equations with antisymmetric random interactions. *J. Phys. Soc. Jpn*. 71: 429-431.

Chesson, P.L. and Warner, R.R. 1981. Environmental variability promotes coexistence in odelin competitive systems. *Am. Nat*. 117: 923-943.

Chon, T.-S., Kwak, I.S., Park, Y.S., Kim, T.H. and Kim, Y.S. 2001. Patterning and short-term predictions of benthic macroinvertebrate community dynamics by using a recurrent artificial neural network. *Ecol. Model*. 146: 181-193.

Chon, T.-S., Park, Y.S., Moon, K.H. and Cha, E.Y. 1996. Patternizing communities by using an artificial neural network. *Ecol. Model*. 90: 69-78.

Chon, T.-S., Park, Y.S., and Cha, E.Y. 2000a. Patterning of community changes in benthic macroinvertebrates collected from urbanized streams for the short time prediction by temporal artificial neural networks. In S. Lek and J.F. Guegan (Eds.), *Artificial Neuronal Networks: Application to Ecology and Evolution* (pp. 99-114). Springer-Verlag, Berlin.

Chon, T.-S., Park, Y.S. and Park, J.H. 2000b. Determining temporal pattern of community dynamics by using unsupervised learning algorithms. *Ecol. Model*. 132: 151-166.

Cody, M.L. and Diamond, J.M. 1975. *Ecology and evolution of communities*. Cambridge, Belknap.

Cohen, J.E., Briand, F. and Newman, C.M. 1990. *Community food webs: data and theory*. Springer-Verlag, Berlin.

Costanza, R. (1992). Toward an operational definition of ecosystem health. In R. Costanza, B.G. Norton and B.D. Haskell (Eds.), Ecosystem health: new goals for environmental management (pp. 239-256). Island Press, Washington, D.C.

Cushing, J.M., Costantino, R.F., Dennis, B., Desharnais, R.A., and Henson, S.M. (2002). *Chaos in ecology: experimental nonlinear dynamics*. Academic Press, San Diego.

Davis, A.J., Jenkinson, L.S., Lawton, J.H., Shorrocks, B. and Wood, S. 1998. Making mistakes when predicting shifts in species range in response to global warming. *Nature* 391: 783-786.

Diamond, J. and Case, T.J. 1986. *Community ecology*. Harper & Row, New York.

Gaston, K.J. and Blackburn, T.M. 2000. Pattern and process in macroecology. Blackwell Science, Oxford.

Gaston, K.J., Blackburn, T.M., and Lawton, J.H. 1997. Interspecific abundance-range size relationships: an appraisal of mechanisms. *J. Anim. Ecol*. 66: 579-601.

Gilpin, M. E. 1979. Spiral chaos in a predator-prey model. *Am. Nat.* 113: 306-308.

Glansdorff, P, and Prigogine, I. 1971. *Structure, stability and fluctuations*. Wiley-Intersciences, Chichester.

Hall, S.D. and Raffaelli, D.G. 1993. Food webs: theory and reality. *Adv. Ecol. Res.* 24: 187-239.

Hall, S.D. and Raffaelli, D.G. 1997. Food web patterns: what do we really know. In A.C. Gange and V.K. Brown (Eds.), *Multitrophic interactions in terrestrial systems* (pp. 395-417). Blackwell Science, Oxford.

Hanski, I.A. and Gilpin, M.E. 1997. *Metapopulation biology: ecology, genetics, and evolution*. Academic Press, San Diego.

Hastings, A., Hom, C.L., Ellner, S., Turchin, P. and Godfray, H.C.J. 1993. Chaos in ecology: Is mother nature a strange attractor? *Ann. Rev. Ecol. Syst*. 24: 1-33.

Hastings, A. and Powell, T. 1991. Chaos in a three species food chain. *Ecology* 72: 896-903.

Haykin, S. 1994. *Neural networks*. Macmillian College Publishing, New York.

Hinton, G.E. and Sejnowski, T.J. 1986. Learning and relearning in Boltzmann machines In D.E. Rumelhart and J.L. McClelland (Eds.), *Parallel distributed processing: explorations in microstructures of cognition* (pp. 282-317). MIT Press, Cambridge.

Holt, R.D. 1977. Predation, apparent competition and the structure of prey communities. *Theor. Popul. Biol.* 12: 197-229.

Holt, R.D. 1993. Ecology at the mesoscale: the influence of regional processes on local communities. In R.E. Ricklefs and D. Schulter (Eds.), *Species diversity in ecological communities: historical and geographical perspectives* (pp.77-88). University of Chicago Press, Chicago.

Holt, R.D. 1997. From metapopulation dynamics to community structure. In I.A. Hanski and M.E. Gilpin (Eds.) *Metapopulation Biology: Ecology, Genetics, and Evolution* (pp.149-164). Academic Press, San Diego.

Hopfield, J.J. 1982. Neural networks and physical systems with emergent collective computational abilities. *Proc. Natl. Acad. Sci. USA* 79: 2554-2558.

Hsu, S.B., Hubbell, S.P. and Waltman, P. 1978. A contribution to the theory of competing predators. *Ecol. Monogr*. 48: 337-349.

Huisman, J. and Weissing, F.J. 1999. Biodiversity of plankton by species oscillation and chaos. *Nature* 402: 407-410.

Hutchinson, G.E. 1961. The paradox of the plankton. *Am. Nat*. 95: 137-145.

Ito, H. and Ikegami, T. 2002. Evolutionary Dynamics of a Food Web with Recursive Branching and Extinction. *Proceedings of Artificial Life VIII, The 8th International Conference on the Simulation and Synthesis of Living Systems*. University of New South Wales, Sydney, NSW, Australia, 9th-13th December, 2002.

Iwasa, Y. and Roughgarden, J. 1986. Interspecific competition among metapopulations with space-limited subpopulations. *Theor. Popul. Biol*. 30: 194-214.

Jansen, V.A.A. and Kokkoris, G.D. 2003. Complexity and stability revisited. *Ecol. Lett.* 6: 498-502.

Jørgensen S.E. 1998. *Integration of ecosystem theories: a pattern*. Kluwer Academic Publisher, Dordrecht.

Jørgensen S.E. 1995a. Exergy and ecological buffer capacities as measures of ecosystem health. *Ecosystem Health* 1: 150-160.

Jørgensen S.E. 1995b. The application of ecological indicators to assess the ecological condition of a lake. *Lakes & Reservoirs: Research & Management* 1: 177-182.

Jørgensen, S.E., Bernard C.P. and Straškraba, M. 2000. Ecosystems emerging: 4. growth. *Ecol. Model.* 126: 249-284.

Kang, D. 1998. *Pulsing and Self-organization*. PhD. Dissertation, University of Florida.

Kay, J.J. and Schneider, E.D. 1992. Thermodynamics and measures of ecological integrity. In D.H. McKenzie, D.E. Hyatt and V.J. McDonald (Eds.), *Ecological indicators* (pp. 159-182). Proceedings of the International Symposium on Ecological Indicators, Fort Lauderdale, Florida. Elsevier, Amsterdam.

Kinzig, A.P., Pacala, S.W. and Tilman, D. 2002. *The functional consequences of biodiversity: empirical progress and theoretical extensions*. Princeton University Press, Princeton.

Kirkpatrick, S., Gelatt, C.D. and Vecchi, M.P. 1983. Optimazation by simulated annealing. *Science* 220: 671-679.

Kohonen, T. 1982. Self-organized formation of topologically correct feature maps. *Biol. Cybernetics* 43: 59-69.

Kohonen, T. 1984. *Self-organization and associative memory*. Springer-Verlag, Berlin.

Lawton, J. 1989. Food webs. In J. Cherrett (Ed.), *Ecological concepts* (pp.43-78). Blackwell Scientific Publications, Oxford.

Lawton, J.H. 1999. Are there general raws in ecology? *Oikos* 84: 177-192.

Lawton, J.H. 2000. *Community ecology in a changing world.* Ordendorf/Luhe: Ecology Institute.

Lek, S., Delacoste, M., Baran, P., Dimopoulos, I., Lauga, J. and Aulagnier, S. 1996. Application of neural networks to modelling nonlinear relationships in ecology. *Ecol. Model*. 90: 39-52.

Lek, S. and Guegan, J.F. 2000. *Artificial neuronal networks: application to ecology and evolution*. Springer-Verlag, Berlin.

Levin, S.A. 1974. Dispersion and population interactions. *Am. Nat*. 108: 207-228.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73: 1943-1967.

Levin, S.A. and Pacala, S.W. 1997. Theories of simplification and scaling of spatially distributed processes. In D. Tilman and P. Kareiva (Eds.), *Spatial ecology: the role of space in population dynamics and interspecific interactions* (pp.271-295). Princeton University Press, Princeton.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. *Bull. Entomol. Soc. Am*. 15: 237-240.

Lippmann, R.P. 1987. An introduction to computing with neural nets. *IEEE ASSP Magazine*, April, 4 – 22.

Loreau, M., Downing, A., Emmerson, M., Gonzalez, A. and Highes, J. 2002a. A new look at the relationship between diversity and stability. In M. Loreau, S. Naeem and P. Inchausti (Eds.), *Biodiversity and ecosystem functioning. Synthesis and perspectives* (pp. 79-91). Oxford University Press, Oxford.

Loreau, M., Monquet, N. and Holt, R.D. 2003. Meta-ecosystems: a theoretical framework for a spatial ecosystem ecology. *Ecol. Lett*. 6: 673-679.

Loreau, M., Naeem, S. and Inchausti, P. 2002b. *Biodiversity and ecosystem functioning. Synthesis and perspectives*. Oxford University Press, Oxford.

Loreau, M., Naeem, S., Inchausti, O., Bengtsson, J., Grime, J.P., Hector, A. *et al*. 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science* 294: 804-808.

Lotka, A.J. 1922. Contribution to the energetics of evolution. *Proc. Natl. Acad. Sci.* 8: 147-151.

Lubchenco, J., Olson, A.M., Brubaker, L.B., Carpenter, S.R., Holland, M.M., and Hubbell, S.P., *et al*. 1991. The sustainable biosphere initiative: an ecological research agenda. *Ecology* 72: 371-412.

Margalef, R. 1968. *Perspectives in ecological theory*. Univ. of Chicago Press, Chicago.

Martinez, N.D. 1991. Artifacts or attributes? Effects of resolution on the little rock lake food web. *Ecol. Monogr*. 61: 367-392.

Maurer, B.A. 1999. *Untangling ecological complexity: The macroscopic perspective*. The University of Chicago Press, Chicago.

May, R.M. 1972. Will a large system be stable? *Nature* 238: 413-414.

May, R.M. 1974a. Biological populations with nonoverlapping generations: stable points, stable cycles, and chaos. *Science* 186: 645-647.

May, R.M. 1974b. *Stability and complexity in model ecosystems*. Princeton University Press, Princeton.

May, R.M. 1999. Unanswered questions in ecology. *Phil. Trans. R. Soc. Lond*. B 354: 1951-1959.

May, R.M. 2001. *Stability and complexity in model ecosystems with a new introduction by the author*. Princeton University Press, Princeton.

McCann, K.S. 2000. The diversity-stability debate. *Nature* 405: 228-233.

McCulloch, W.S. and Pitts, W. 1943. A logical calculus of the ideas imminent in nervous activity. *Bull. Math. Biophysics* 5: 115-133.

Mejer, H. and Jørgensen, S.E. 1979. Exergy and ecological buffer capacity. In S.E. Jørgensen (Ed.), *State-of-the-art in ecological modeling* (pp. 829-846). Proceedings of the conference on ecological modeling, Copenhagen, Denmark. August, 1978.

Menge, B. 1995. Indirect effects in marine rocky intertidal interaction webs: patterns and importance. *Ecol. Monog*. 65: 21-74.

Minshall G.W. 1983. Stream ecosystem theory: a global perspective. *J. N. Am. Benthol. Soc.* 7: 263-288.
Muko, S. and Iwasa, Y. 2000. Species coexistence by permanent spatial heterogeneity in a lottery model. *Theor. Popul. Biol.* 57: 273-284.
Naeem, S., Thompson, L.J., Lawler, S.P., Lawton, J.H. and Woodfin, R.M. 1994. Declining biodiversity can alter the performance of ecosystems. *Nature* 368: 734-737.
Namba, T. 1984. Competitive co-existence in a seasonally fluctuating environment, *J. Theor. Biol.* 111: 369-386.
Namba, T. and Takahashi, S. 1993. Competitive coexistence in a seasonally fluctuating environment: II. Multiple stable states and invasion success. *Theor. Popul. Biol*. 44: 374-402.
Namba, T., Umemoto, A., and Minami, E. 1999. The effects of habitat fragmentation on persistence of source-sink metapopulations in systems with predators and prey or apparent competitors. *Theor. Popul. Biol*. 56: 123-137.
Nee, S. and May, R. M. 1997. Extinction and the loss of evolutionary history. *Science* 278: 692-694.
Odum, H.T. 1983. *Systems ecology: an introduction*. John Wiley & Sons, New York.
Odum, H.T. and Pinkerton, R.C. 1955. Time's speed regulator: the optimum efficiency for maximum power output in physical and biological systems. *Am. Scientist* 43: 331 -343.
Oh, J.-H., Kwon, C. and Cho, S. (Eds.) 1995. *Neural networks: the statistical mechanics perspective*. World Scientific, Singapore.
Okubo, A. 1980. *Diffusion and ecological problems: mathematical models.* Springer-Verlag, Berlin.
Okubo, A. and Levin, S.A. 2001. *Diffusion and ecological problems: modern perspectives.* Springer-Verlag, New York.
Perry, J.N., Smith, R.H., Woiwod, I.P. and Morse, D.R. 2000. *Chaos in real data: the analysis of non-linear dynamics from short ecological time series*. Kluwer Academic Publisher, Dordrecht.
Patten, B.C. and Jorgensen S.V. 1995. *Complex Ecology: the part-whole relation in ecosystems*. Prentice Hall, Englewood Cliffs.
Pimm, S.L. 1982. *Food webs*. Chapman & Hall, New York.
Pimm, S.L., Lawton, J.H. and Cohen, J.E. 1991. Food web patterns and their consequences. *Nature* 350: 669-674.
Polis, G.A. 1991. Complex trophic interactions in deserts: an empirical critique of food-web theory. *Am. Nat.* 138: 123-155.
Polis, G.A., Anderson, W.B. and Holt, R.D. 1997. Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. *Ann. Rev. Ecol. Syst*. 28: 289-316.
Post, D. M. 2002. The long and short of food chain length. *TREE* 17: 269-277.
Raffaelli, D., van der Putten, W.H., Persson, L., Wardle, D.A., Petchey, O.L., Korichaeva, J., van der Heijiden, M., Mikola, J., and Kennedy, T. 2002. Multi-trophic dynamics and ecosystem processes. In M. Loreau, S. Naeem and P. Inchausti (Eds.), *Biodiversity and ecosystem functioning: Synthesis and perspectives* (pp. 147-154). Oxford University Press, Oxford.
Rapport, D.J. 1995. Preventive ecosystem health care: the time is now. *Ecosystem Health* 1: 127-128.
Recknagel, F. 2003. *Ecological informatics: understanding ecology by biologically-inspired computation*. Springer, Berlin.
Recknagel, F., Harkonen, F.M. and Yabunaka, K.I. 1997. Artificial neural network approach for modelling and prediction of algal blooms. *Ecol. Model*. 96: 11-28.
Ricklefs, R.E. 1987. Community diversity: Relative roles of local and regional processes. *Science* 235: 167-171.
Ricklefs, R.E. and Schluter, D. 1993. *Species diversity in ecological communities: historical and geographical perspectives*. University of Chicago Press, Chicago.
Rosenzweig, M.L. 1995. *Species diversity in space and time*. Cambridge University Press, Cambridge.
Roughgarden, R. and Iwasa, Y. 1986. Dynamics of a metapopulation with space-limited subpopulations. *Theor. Popul. Biol*. 29: 235-261.
Rumelhart, D.E. and McClelland, J.L. 1986. *Parallel distributed processing: explorations in the microstructure of cognition*. MIT Press, Cambridge.
Salomonsen, J. 1992. Examination of properties of exergy, power and acendency along a eutrophication gradient. *Ecol. Model*. 62: 171-181.
Scardi, M. 1996. Artificial neural networks as empirical models of phytoplankton production. *Mar. Ecol. Prog. Ser.* 139: 289-299.
Schulze, E.-D. and Mooney, H.A. 1993. *Biodiversity and ecosystem function.* Springer-Verlag, Berlin.
Skellam, J.G. 1951. Random dispersal in theoretical populations. *Biometrika* 38: 196-218.

Straškraba, M. 1979. Natural control mechanisms in models of aquatic ecosystems. *Ecol. Model*. 6: 305-322.

Strong, D.R., Jr., Simberloff, D., Abele, L.G. and Thistle, A.B. 1984. *Ecological communities: conceptual issues and the evidence*. Princeton University Press, Princeton.

Tilman, D. and Kareiva, P. 1997. *Spatial ecology: the role of space in population dynamics and interspecific interactions*. Princeton University Press, Princeton.

Tilman, D., Wedin, D. and Knops, J. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature* 379: 718-720.

Ulanowicz, R.E. 1980. An hypothesis on the development of natural communities. *J. Theor. Biol.* 85: 223-245.

Vance, R.R. 1978. Predation and resource partitioning in one predator-two prey model communities. *Am. Nat.* 112: 797-813.

Whittaker, R.H. and Woodwell, G.M. 1971. Evolution of natural communities. In J. A. Weins (Ed.), *Ecosystems structure and function* (pp. 137-159). Oregon State Univ. Press, Corvallis.

Winemiller, K.O. 1990. Spatial and temporal variation in tropical fish trophic networks. *Ecol. Monogr*. 60: 331-367.

Wootton, J.T. 1994. The Nature and consequences of indirect effects in ecological communities. *Ann. Rev. Ecol. Syst*. 25: 443-466.

Yodzis, P. 1988. The indeterminacy of ecological interactions as predicted through perturbation experiments. *Ecology* 69: 508-515.

Yokomizo, H., Yamashita, J. and Iwasa, Y. 2003. Optimal conservation effort for a population in a stochastic environment. *J. Theor. Biol*. 220: 215-231.

Zurada, J.M. 1992. *Introduction to artificial neural systems*. West Publishing, St. Paul.

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FELIX MÜLLER & BAI-LIAN LI

CHAPTER 3

COMPLEX SYSTEMS APPROACHES TO STUDY HUMAN-ENVIRONMENTAL INTERACTIONS: ISSUES AND PROBLEMS

1. INTRODUCTION

As any science, ecology is operating within a broad range of objectives, situated between very basic researches on the one hand and applications of the knowledge which has been elaborated throughout these fundamental research activities on the other. But in contrast with most other sciences, ecologists have to bear a certain societal responsibility concerning their contributions to find the best sketch of future developmental directions of the human environment. This "big project" cannot be conducted "in ecological isolation", because man provides the dominating constraints for ecological dynamics, and thus his and her activities have to be incorporated into the applied research agendas of ecologists. Therefore, it seems to be extremely important to include humanities into ecological research framework, or at least to provide potential levels-of-linkage which could be basic starting points for interdisciplinary environmental analyses. Recent environmental, economic and political demands are also requiring better understanding of the linkage between the ecological and human social systems, especially in the context of the development of management strategies for a sustainable world. We are facing several environment-related threats to human welfare, health and security in the 21st century. The respective questions for a complex system approach to such dynamic human-environmental interactions are extremely important and significant for the scientific progress, as well as for the political decision-making and development processes in the face of inevitable environmental change.

We are aware that many different approaches for this "big project" have already been developed, such as ecological economics, ecological engineering, ecotechnology, ecological planning, human ecology, and so on. And we do take into account that these scientific fields have produced many stimulating concepts, methods and results. But, what we are missing in this elaborate group of sub- and inter-disciplines is an approach of systems ecology to cope with issues and problems associated with human-environmental interactions.

Originating in theoretical concepts on ecosystems, and knowing the advantages and the problems of systems approaches, we have tried to formulate some hypotheses and ask some questions about this open field of science which are

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principally based on the discussions around the symposium we organized during the INTECOL World Congress in Seoul in 2002. Consequently we have not tried to produce new results in this essay but to start or to enhance a discussion about the potential of systemic investigations to better contribute to the solution of the urgent environmental problems we are now facing.

Taking the systems perspective, the coupled human-environmental entities have to be investigated as observer-defined abstractions which are characterized by their mutual interactions. They comprise of very different structural elements; while the focal ecological subsystems are, for example, atmosphere, soil, aquifer, producers, consumers, or mineralizers, the group of human sub-systems includes aspects such as population dynamics, economic parameters, sociological structures, norms or cultural values, and traditions. The relations between these subsystems – the functional features – are controls, regulations, and flows of water, information, energy or nutrients. In addition to these mutual interrelations, human functions also include activities like nutrition, work, education, communication, recovery, logistics, transports, etc. Therefore, human-ecological systems form extremely complex units which can only be understood on the basis of their mutual interactions. These can often be reduced to the exergetic and entropic flows of information, energy, matter and water, but for sure, this abstraction is not enough to form a satisfying representation of the whole. Thus, such a systems approach is correlated with many problems and questions. But nevertheless, it appears to be promising and worthwhile to be tried. In the following we have collected some important aspects and fields of (solvable) problems which hopefully can underline this optimism.

2. TEN ISSUES ASSOCIATED WITH COUPLED HUMAN-ENVIRONMENTAL SYSTEMS APPROACHES

To clarify the potential of systems approaches we have selected ten significant issues and related problems which are briefly described in the following paragraphs. The items reach from the demands of the sustainability concept to the general problems of systems analysis and environmental indication. This overview will be followed by a number of key questions which have been selected to describe potential research agenda for the future.

2.1. The rational evidence of sustainability–a broadly accepted but inconcrete concept

Sustainable development has been accepted by nearly all countries as a guiding principle for their developmental policies. It has been conceived as an overall, interdisciplinary enterprise which in fact primarily appeals to features of global politics, such as equality, freedom, or democracy, to sociological features like solidarity, or cultural diversity, and to a healthy environment. After more than ten years of discussion, nearly everybody knows the formulation of the WCED (1987, p. 42) that "sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own

needs." To approximate that dynamic strategy, sustainable development has to include three kinds of considerable relationships (Hauff 1987):

- interactions between human needs and the capacities of nature (carrying capacity),
- interactions between the rich and the poor (intragenerational equity), and
- interactions between the present and future generations (intergenerational equity).

Sustainability furthermore demands for different types of our fundamental attitudes. There are cultural goals (to reach an interregional, long-term protection of cultural identities of human subsystems and populations), social targets (to reach an interregional, long-term protection of different life styles in a context of social justice), economic aspects (to reach a long-term protection of the profitableness of the natural resources) and – last but not least – ecological items (to reach a long-term protection of the viability of human populations in a self-regulated, resilient environment), which have to be combined. This list makes clear that sustainability is a strictly normative concept with an overall anthropogenic fundament which can be realized only if interdisciplinary approaches are taken into account. Stressing that last point, systems analysis should provide the tools to realize that high degree of necessary integration on a scientific basis.

2.2. The ambitious demands of sustainability–paradigmatic changes are required

Realizing that sustainable development is a preliminary anthropocentric strategy, the central goals have to be the protection of natural resources, which means the protection of future life support systems for mankind and the avoidance of risks to human welfare and health. If we pay a closer look at these aims it will turn out that these basic requirements are purely ecological demands. As these demands have to be fulfilled in landscape-level management, a number of prerequisites have to be met to apply really sustainable strategies (see Table 1). We believe that these demands have caused shifts of paradigms in many related scientific disciplines, and ecology itself has also been affected by those requirements.

Table 1. Some basic demands for the development of strategies for a sustainable landscape management

Long-term strategies	think in generations
Multi-scale strategies	human vs. ecological time scales
Interdisciplinary strategies	ecology is only a part of it
Holistic strategies	structures and functions
Realistic strategies	include uncertainties
Nature-oriented strategies	take nature as a model
Theory-based strategies	make sure correctness
Hierarchical strategies	realize constraints and scales
Goal oriented strategies	joint definition of the targets

As these points seem to have very eminent consequences for the way we investigate human-environmental systems, we are going to describe these demands in more detail:

Long-term strategies: They have to take into account that the time scale of the assessed anthropogenic process generally should be adapted to the time scales of the respective natural processes. They operate relatively on very long time scales, such as evolution or succession. The speed of natural adaptation therefore usually is much smaller than the speed of man's technological changes.

Multi-scale strategies: A sustainable landscape management should realize that natural processes are organized and regulated in accordance with their spatial and temporal characteristics (Allen and Starr 1982, O'Neill *et al*. 1986, Müller 1992, Li 2000a, b). Therefore, at least three different scales have to be analyzed if the management result shall meet the sustainability demands: the focal scale of the actual problem, the constraining superior hierarchical level, and the inferior level which determines the biotic potential of the system (O'Neill *et al*. 1989). Analyzing the extents and frequencies of potential disturbances thus results in a discrimination of potentially influenced natural processes, which operate in similar scales (Norton and Ulanowicz 1993).

Interdisciplinary strategies: To derive measures for a sustainable management of the ecosphere, ecological arguments have to be put into a framework that also includes cultural, social and economic aspects. To develop respective objectives and methods the competent sciences have to cooperate intensively (Jüdes 1998).

Holistic strategies: Sustainable strategies have to perceive the relationships between man and nature as entities which follow the general laws of open systems. To deal with these functional units, the techniques of systems analysis should be applied. This means that the enormous significance of indirect effects must be paid attention to and that the approach is capable of coping with the high complexity of the investigated systems (Li 2000b).

Realistic strategies: It is important to inform the responsible decision makers about the (in)validity of the ecological data used and the prognoses worked out (Breckling 1992). All ecological information should be escorted by information on potential uncertainties, methodological mistakes, and statistical inaccuracies. Also, it is important to take into account the possibilities of irreversibility, and the natural integration of destructive pathways which are normal constituents in all ecological systems (Holling 1986).

Nature-oriented strategies: As has been mentioned in the beginning of this text, in search of sustainable strategies, nature seems to be a good model (Bossel 1998). Therefore, the potential reaction patterns of natural systems in many cases can be taken as guidelines for human reactions and management activities.

Synergetic and theory-based strategies: The correctness of the assumptions which are made throughout decision processes will be the higher, the deeper the theoretical foundation of the applied concept is. Thus, approaches of systems science and synergetics can be very helpful to understand and foresee the behaviour of complex entities. Applying these sciences, it turns out that one of the most important features of such systems is their potential for self-organization (*e.g.*, see

Müller *et al*. 1997a, b, Li 2000b). This ability should be supported in respect of any management activity.

Limiting and hierarchical strategies: All sustainable activities have to accept the natural system of constraints, which the investigated entity operates in. Ecological assessments thus have to look for the system's carrying and assimilation capacities. Also, economical attitudes have to realize that the natural resources are scarce. Thus, cautious use of non-renewable resources, and the preferable use of renewable resources that does not exceed the assimilation capacity of the ecosystems should be a characteristic for the aspired procedure.

Goal-oriented strategies: A preferable concept of introducing ecological requirements bases on the definition of ecological quality objectives. If these targets are derived on the basis of the above mentioned principles, and if holistic objects of protection are discussed, a big step towards sustainable management strategies can be taken.

All these point seem to underline the high potential of systems ecology to widen the scope towards a more applicable direction, but they also elucidate the problems that are associated with such attempts.

Reflecting the basic demands of the sustainability concept, two further circumstances have to be stressed. The first point affects the spatio-temporal environment. Ecosystems must be considered as functional hierarchies which operate on very different spatial and temporal scales; they must not be investigated as isolated units but (always) in the context of the surrounding landscape and the other corresponding that potentially influenced ecological systems. And they must be managed on the basis of different temporal horizons which also include the durations of succession and arguments that concern the long-term structural and functional adaptability of the systems (*e.g*., Chen *et al*. 2003).

The second aspect refers to a new protective goal, adaptability and its systemic fundamentals: all ecosystems, even drastically disturbed and comprehensively managed ones, are basing on self-organized processes (Müller *et al*. 1997a). They are fundamentals of the system's growth and development, they determine all features of stability and resilience, and they are responsible for the execution of all structural and functional changes. Therefore, the ability of ecosystems to develop in self-organized process sequences must be an important target of sustainable landscape management. This ability (the system's capacity for self-organization) has to be protected, optimized and developed, and therefore, the degree, the duration, and the efficiency of the self-organizing processes which have taken place up to the focal point in time, should be central arguments of environmental evaluation. Thus the aspired criterion, ecosystem integrity, can serve as a guideline for the protection, preservation and support of the performance of ecological interactions and systems, also representing the utility of natural goods and services.

2.3. Ecological science has changed–systems ecology has grown out of puberty

In the last decades, some very efficient modifications have also occurred in ecological and environmental sciences. Before all, the evidence of the systems

perspective and the respective utilization of ecological modeling techniques have increased enormously throughout this period. As a consequence of the growing number of ecosystem research initiatives, this development was accompanied by several changes in basic ecological concepts, accelerating holistic approaches which are capable to integrate the methods and results of reductionistic investigations. As a consequence, the complexity of ecological systems has become a subject of research, while it had been neglected wherever possible in the past.

In Table 2 some features of this development are sketched. Concerning the human-ecological systems, many important consequences can be derived from those features. For example, the acceptance of the general irreversibility of environmental changes has provoked a paradigm shift from the stability concept to a theory of change and development where steady states represent only relatively short periods on certain temporal scales. This fact leads to a relativation of the idea of predictability: bifurcations and non-linearities are responsible for the fact that predictability is today understood more as an exception than a rule.

Table 2. Some recent developments in ecological science

From	*To*
Mono-scale analysis	multi-scale analysis
Neglecting complexity	exploring complexity
Reductionistic analysis	holistic synthesis
Reversible reactions	irreversible reactions
Continuity	bifurcations and phase transitions
Linearity	non-linearity
Chains	webs and networks
Stability	steady state and development
Closed systems	open systems
Equilibrium	non-equilibrium
Predictability	non-predictability
Strong causality	weak causality and possibility

As those systems arguments have taken over in some branches of ecology, further changes have occurred. Systems scientists more and more look for indirect effects and feedbacks in the ecological networks, and in many case studies it was shown that the indirect modifications are able to dominate the direct linkages. Also the search for chronicle effects has been enhanced, and de-localized effects have become more and more obvious, e.g. as important arguments throughout the climate change debate. Last but not least the comprehension of ecological units as self-organized systems has provoked a new way of thinking about systems development, disturbance and restoration.

These young experiences could not only be applied in the field of basic systems research but they also include a high potential to be used for the optimization of holistic environmental management conceptions.

2.4. Environmental Management Is Changing–From Bottom Up to Top Down Approaches

Of course, the scientific ideas of systems ecology have also had effects in environmental management. These consequences have been enormously accelerated by the demands of the sustainability principle (see above). Thus, in many fields of environmental administration, interdisciplinary structures have become more and more accepted – although the modifications take a very long time due to psychological arguments: integration and interdisciplinarity need team work and the self-comprehension of being "only" a part of a bigger unit. Nevertheless, sectors often are no more investigated or managed as isolated entities but as parts of systems with a high degree of interrelations. Recognition of such a high degree of interrelations requires changes in our management practice. The table 3 below lists some recent changes in environmental management. To support these political shifts, system ecology should put more emphasis into the development of tools for supporting a more systems-based management.

Table 3. Some recent changes in environmental management

From	*To*
Instrumental orientation	policy mix
Single-problem view	sustainability
Disciplinary structures	interdisciplinary structures
Reductions to sectors	coupling different sectors
Focus on compartments	focus on entire ecosystems
Maximum load	disturbance reduction
Constraints of resorts	integrating resorts
Weak information base	communication
Ecology *vs*. Economy	ecology *and* economy
Top-down regulation	participation
National limitation	international cooperation

2.5. There is a political demand for integration–do policy-makers act more quickly than ecologists?

As a case study demonstrating these changes, we can quote the German Law for Nature Protection, which has been established in 2001. In this law and its comments we can find innovative formulations like "integrated system protection", "coupling of structures and functions", "performance and functionality of natural systems", and "networks of interactions". And taking a look at the Rio declaration from 1992, ecosystem conservation concepts like ecosystem *health* and ecological *integrity* have been quoted as political targets long ago. It is astonishing that the translation of these ideas into national policies has been less successful than the implementation into scientific thinking. Ecosystem *health* was introduced by Rapport (1989). The concept is based on a systems approach (see Table 4), and it therefore reflects a modern attitude of nature protection. Haskell *et al*. (1993) have defined an

ecosystem as a healthy one if it is stable and sustainable - that is, if it is active and maintains its organization and autonomy over time and if it is resilient to stress. Costanza (1993) proposed the idea that an ecosystem's health can be evaluated on the basis of the three factors: vigor (productivity and total systems throughput), organization (diversity and flow density), and resilience, which represents a scope for growth. Table 4 may be used to demonstrate the broad correspondence between the general systems approaches and the fundamental principles of ecosystem health.

The concept of ecological *integrity* originates in a number of sources, and therefore many different aspects can be found in the literature. This may be documented by a look at some different definitions. For example, Karr (1992) describes integrity as an ecological quality or state of being complete and undivided, which can be characterized by a minimal necessary external support for management purposes. Angermeier and Karr (1994) define integrity as the capability of a system or a spatial area of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat in the region. Other authors expand that ecological frame and integrate the ability of a system to support services of value for humans from an anthropocentric point-of-view. Trying to characterize integrity from a systems perspective, Kay (1993) states that integrity encompasses (a) ecosystem health (the ability of an ecosystem to maintain at the optimum operating point under normal conditions), (b) resilience (the ability to return to an optimum operating point after stress), and (c) the self-organizing capacity which enables the system to continue developing and evolving. Similar to this attitude, Müller (1998a) has proposed to call an ecosystem integer, if it is able to maintain its organization and steady state after small disturbances and if it has a sufficient adaptability and developmental capacity to continue the self-organized development. Barkmann *et al*. (in press) describe ecosystem integrity as "a comprehensive guideline for the sustainable management of the balance of nature. Integrity represents the ecological 'brick stone' of sustainable development. The scientific nucleus of integrity is the potential for self-organization of an ecosystem. Integrity comprehends nature under systemic, hierarchical and media-integrating viewpoints."

Table 4. Axioms of ecosystem health, after Costanza et al. (1993). The listed parameters reflect the basic system related fundamentals of the health approach which are also valid for the concept of ecological integrity

Dynamism	Nature is a set of processes, more than a composition of structures
Relatedness	Nature is a network of interactions
Hierarchy	Nature is built up by complex hierarchies of spatio-temporal scales
Creativity	Nature consists of self-organizing systems
Different fragilities	Nature includes various sets of different resiliences

What we can state here is the fact that the fundamentals for a more systems based ecological management scheme have been worked out, several attempts have been conceived, and the political sphere seems to be ready to use these ideas, it has even adopted them into modern environmental laws. This should be a good point of departure for an intensified use of these ideas from systems ecology.

2.6. Science Is Not Ready To Fulfil the Political Demands–Missing Concepts, Methods, Models and Applications

Assuming that undefined notions in laws do only have a minor influence, a central primary target should be the elaboration of useable and broadly accepted definitions for the systems preservation concept elements. Furthermore science still has to deliver answers and tools concerning the following questions:

- What exactly is ecosystem protection and how can the components of the concept be defined?
- Which tools can we use to evaluate the states of ecosystem?
- How can we integrate ecosystem protection and the notion of life support systems?
- How can ecological functions be better integrated into environmental management?
- How to characterize and measure the functionality of ecosystems or ecosystem performance?
- How can concepts like health or integrity be better incorporated into sustainable landscape management strategies?

These questions include many tasks for environmental sciences which can be solved rather easily because there is a good base of knowledge concerning the ecological systems perspective. Scientists should speed up because the further development of these concepts depends on their inputs. Although it is easy for politicians to argue with fuzzy conceptions, a concrete application is only possible on the basis of productive answers to the questions mentioned above. Bridging various concepts, methods, models and applications is needed to move this issue forward, and we should strongly encourage our scientists to pursue this direction and make the science ready for policy-making.

2.7. Human systems provide new dimensions–what is "quality of life" and how can we quantify it?

While ecologists are usually arguing about habitats, abundances, patterns, storages or flows, the collaboration with social sciences brings about very distinct features. The respective dimensions are referring to items like

- economic welfare
- money, influence, and power
- ethical values
- legal norms and laws
- feelings and emotional preferences
- esthetical values, and beauty

- social welfare
- consciousness and “Zeitgeist”
- individual or joint patterns of environmental perception
- political decision processes.

Some of these characteristics appear to be rather foreign for ecologists, and in some cases their quantifications are more than fuzzy. Nevertheless, the beauty of a landscape will provide much more arguments to the public than a special and extremely rare combination in the food webs of that area. Thus, coping with the interdisciplinary challenge, scientific concepts have to be developed which enable us to link ecological facts with evaluative motivations.

2.8. Linkages Are Difficult–No Joint Dimensions for Human and Ecological Systems

There are no consensual dimensions which would make such a linkage possible, although many ideas have been discussed in the literature. All of them are accompanied by problems, which we summarize in the following list:

Money is used as a focal dimension by ecological economists. This is consequent from the economic point-of-view, but many ecological items and many ecosystem services cannot really be quantified on a monetary basis. For example, what is the value of a plant that has gone extinct? How much costs and how much benefit does a forest produce? What is the value of a nice landscape? How much money can we gain from a high exergy consumption or from an optimal entropy production?

Some of these questions seem to be answered if people are asked for their *willingness to pay* for a certain ecological performance. Regrettably the answers in a questionnaire differ enormously from reality; the motivation to pay for a walk through a forest might rapidly slow down if the visitor really has to pay for it.

Another approach of a monetary evaluation of ecological performances is based on the *avoidance costs* which are saved by a nature-near management of the environment. Also these calculations are far from realization, and their quantitative basis is rather fuzzy in many cases. Furthermore they cannot be proved (because they are avoided).

Several approaches have been developed which are based on the ideas of the *functions of nature and ecosystem services*. They seem to be very promising. But things become harder if these objects are quantified on the basis of money, because in that case all of the drawbacks mentioned above are applied, and thus the described uncertainties come into the game.

Therefore, the question is: do we really have to reduce the totally different systems into one dimension? Our hypothesis states that this is not necessary. Doing it, we press very different circumstances into an extremely artificial envelope, producing extremely artificial results. Thus, the basis of coupled human-environmental investigations should be a multidimensional one. For example, we can estimate the economic costs and benefits in the secure economic terrain. And we can accomplish these data with additional results which characterize the natural functionality, e.g. by indicating the functions of nature as shown in Figure 1 on the basis of their real quantitative expressions.

2.9. Systems approaches suffer from complexity–complexity reduction as the focal challenge

Systems approaches in ecological studies have made considerable progress in understanding the fundamental ecological interactions in relatively "pristine" ecosystems, especially through the establishment of systems ecology and ecosystems theory. Human systems – also regarded as complex – have also been analyzed from a systems perspective. There are many models on basic economic and social processes, as well as practical applications in urban and regional planning, transportation system design, etc. As we discussed above, however, a coupled human-environmental system is even more complicated than either system alone. Mathematically speaking, finding the minimal causal structure of such a complex system based on a set of observations is computationally intractable for even moderately sized systems; it is NP-hard problem (Krupa 2002). Traditional systems approach can not overcome such a difficulty because many complex human-environmental systems are not well behaved and frequently undergo sudden changes that suggest that the functional relations that represent them are not differentiable. So far we do not have a good understanding of the systems. We cannot explain them with confidence, and we even have trouble describing them.

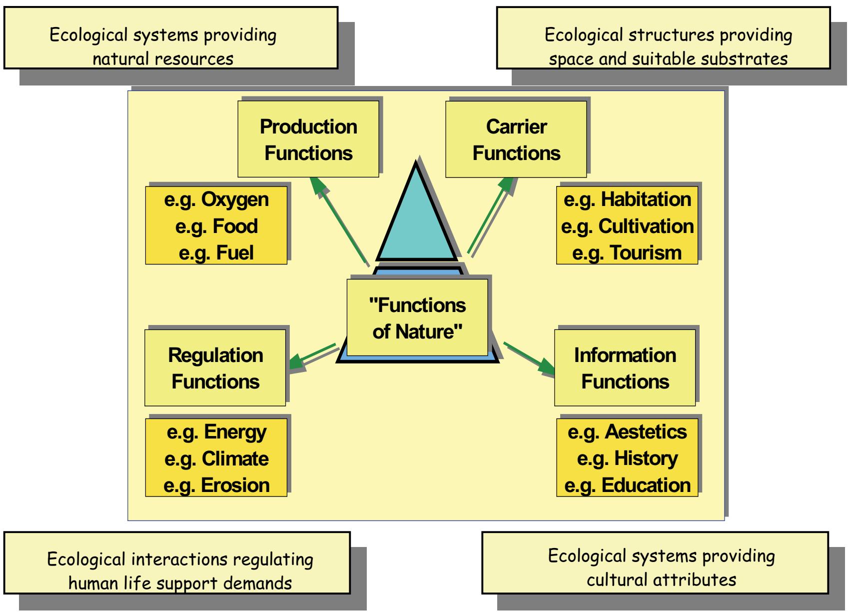

Figure 1. Functions of nature after de Groot (1992).

For example, consolidative modeling is in many ways the standard approach to model development and use, building a model by consolidating known facts into a

single package and then using it as a surrogate for the actual system. This approach to modeling and simulation is based on an assumption that we can predict what will happen. This assumption motivates building a single model that best represents what we know about the system. This model is "validated" by comparison with data. Validated models are used to design policies or systems by seeking designs that optimize cost/benefit measures against the best estimate model. Where successful, it is very powerful tool for understanding the behavior of complex systems. Unfortunately, the consolidative approach is not always possible due to the nature of the systems complexity we discussed above, especially for coupled human-environmental systems analysis. When we are unable to discover a model that predicts system behavior, the entire methodology built upon best estimate modeling becomes foundationless.

The employment of complexity as an explanatory principle has become fashionable with the work of von Neumann even von Neumann himself was never very specific about what complexity actually meant. In the 1950's, he predicted that the elucidation of the concepts of complexity and complication would be the task of science in the 20th century as it was in the 19th century for the concepts of energy and entropy. It appears that this prediction come true.

Complex systems self-organize themselves into states of greater complexity. That behavior is not predictable from knowledge of the individual elements, no matter how much we know about them. But it can be discovered by studying how these elements interact and how the system adapts and changes throughout time. This new, emergent behavior of the system is important for understanding how human-environmental system operates on the macroscopic level (Li 2000b).

For many real decision-making problems the nonequilibrium dynamics are key, uncertainty about the future is real and fundamental, and the best language to capture our understanding of process may not be the best language to debate our judgments about outcomes. In such a case, exploratory modeling may be useful. Exploratory modeling is the use of series of computational experiments to explore the implications of varying assumptions and hypotheses. This modeling approach can be understood as search or sampling over an ensemble of models that are plausible given a priori knowledge or are otherwise of interest. The focus of exploratory modeling is the virtual ensemble of models, all of which are plausible or interesting in the context of the research or analysis being conducted. This ensemble is generated by the uncertainties associated with the problem of interest, and is constrained by available data and knowledge. Another promising approach is multi-agent system approach. Such an approach is designed to obtain an ensemble of interconnected agents that can operate beyond the capabilities of any individuals. Cooperation and competition among interacting agents are regarded as a foundation of self-organization of the system. An agent-oriented view of the world has become fashionable in the science of complexity. Some agent-based decision-making tools for ecosystems management have been developed.

Complexity can be classified into structural and functional complexities, or static, dynamical, and even self-organized and evolving complexities. The understanding of coupled human-environmental systems depends on our ability to handle complexity properly. Complexity reduction or system simplification is very

important, and also a focal challenge for systems ecologists. Surely hierarchy theory and scaling methods will help us to achieve the goal. For example, using time scale hierarchy, essential aspects of complex causal dynamic system (or models) can be captured and detected by simpler mathematical models without sacrificing too much of the realism provided by the original ones (Øyehaug *et al*. 2003). Fuzzy logic and systems theory is another tool we can use for reducing complexity (Li 2001). Data mining and knowledge discovery techniques are also very promising in dealing with complexity, especially for the increasing flow of ecological, economic and social data. Wang *et al*. (2001) successfully constructed a knowledge mining system to assess the world's sustainability based on the Human Development Database of the United Nations Development Programme. Using indices and indicators is another very practical way to reduce complexity. Fuzzy modeling, data mining and knowledge discovery and other complex systems approaches have been used for developing better indicator systems for system characterization and policy-making.

2.10. Using Indicators, Many Problems Arise–Is Indication a Second-Class-Information?

As it has been shown above, one measure to reduce the complexity of human-environmental systems is a representation of the most significant parameters of the observer-defined system by indicators. They are used to substitute direct measurements, because in complex systems too many variables would be necessary, too many relevant interrelations can be defined, and the price for such a detailed system analysis simply would be too high. Such attributes should be easily measurable, they should be able to be aggregated up to a certain level, and they should depict the investigated relationships in an understandable manner. As the following list shows, there are also high requirements for the quality of such indicator sets, and therefore in many instances they represent a compromise between many different requirements. The basic demands for indicator sets are the following:

- clear representation of the *indicandum by the indicator*
- optimal *sensitivity* of the representation
- high *transparency* of the derivation strategy
- *validity* and representativeness of the available data sources
- *comparability* and correct *scaling* in indicator sets
- optimal degree of *aggregation* (correct vs. understandable)
- definite *normative loadings*
- high *political relevance*
- direct *relation to management* actions
- high utility for *early warning* purposes

Although there will always remain disequilibria between the indicator and the indicandum, their application seems to be the most promising way of human-environmental systems analysis. While the systems methodology will optimize the scientific correctness of the indicator sets, their potential for aggregation will increase the utilization by decision makers. Nevertheless, the derivation of integrated indicator sets is still in a rather juvenile stage, thus a lot of emphases should be invested into this field of applied systems ecology.

3. SOME KEY QUESTIONS

We hope that it could be shown that there is a high potential in complex systems approaches to study coupled human-environmental systems. As a consequence of those issues and problems mentioned in this essay, there are still rather basic questions which have to be solved:

- Which is the significance of ecological arguments, and which role will natural science play in future within the normative and interdisciplinary concept of sustainable development?
- How can the methodological demands which are derivable from the principle of sustainability, be transformed into applicable strategies for sustainable landscape management?
- Which cognitions from systems ecology can be used for the analysis of human–environmental systems?
- How can the transition of environmental management into the direction of a system-level application be accelerated, and how can the prevailing psychological impediments be overcome?
- Which tools does modern environmental management need from ecologists, and which tools can they offer?
- How can the various undefined terms of modern ecological concepts be transformed into hard and concrete principles with exact and accepted comprehensions in jurisdiction?
- Which human dimensions should be coupled with ecosystem science to support sustainable strategies?
- How to find the optimal intersections between ecological and socio-economic systems?
- Which are the potentials and which are the limitations of modeling human-environmental systems?
- How to identify optimal indicator sets?

New methods and approaches in the science of complexity have provided us a new opportunity to comprehensively understand the coupling dynamics of human and ecological systems, and the prospects of sustainable management across a range of spatial and temporal scales. New complex systems approaches also shed a new light on co-evolution trajectories and the resilience of coupled social and ecological systems. We are looking forward to see the development and progress of human-environmental systems analysis in the context of the science of complexity and we hope that in next INTECOL Congress a significant progress can be documented in this interesting and emergent field of science.

4. REFERENCES

Allen, T.H.F. and Starr, T.B. 1982. *Hierarchy - Perspectives for Ecological Complexity*. The University of Chicago Press, Chicago.

Angermeir, P.L. and Karr, J.R. 1994. Biological integrity versus biological diversity as policy directives: protecting biotic resources. *Bioscience* 44: 690-697.

Barkmann, J., Baumann, R., Breckling, B. Irmler, U., Müller, F., Noell, C., Reck, H., Reiche, E.W. and Windhorst, W. (in press). Ökologische Integrität als Beschreibungsmaßstab und Leitbild für Ökosystemschutz und nachhaltige Entwicklung.

Bossel, H. 1998. Ecosystems and society: orientation for sustainable development. In F. Müller and M. Leupelt (Eds.), *Eco Targets: Goal Functions and Orienters* (pp. 366-380). Springer, Berlin.

Breckling, B. 1992. Uniqueness of ecosystems versus generalizabilty and predictability in ecology. *Ecological Modelling* 63: 13-28.

Chen, X., Li, B.L. and Lin, Z.S. 2003. The acceleration of succession for the restoration of the mixed-broadleaved Korean pine forests in Northeast China. *Forest Ecology and Management* 177: 503-514.

Constanza, R. 1993. Towards an operational definition of ecosystem health. In R. Constanza, B.G. Norton and B.D. Haskell (Eds.), *Ecosystem Health* (pp. 239-256). Washington.

Constanza, R., Norton, B.G. and Haskell, B.D. 1993. *Ecosystem Health*. Washington.

De Groot, R.S. 1992. *Functions of Nature*. Wolters-Noorhoff.

Haskell, B.D., Norton, B.G. and Constanza, R. 1993. Introduction: What is ecosystem health and why should we worry about it? In R. Constanza, B.G. Norton and B.D. Haskell (Eds.), *Ecosystem Health* (pp. 3-22). Washington.

Hauff, V. 1987. *Unsere Gemeinsame Zukunft*. Der Brundlandt-Bericht der Weltkommission für Umwelt und Entwicklung. Greven.

Holling, C.S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. In W.M. Clark and R.E. Munn (Eds.), *Sustainable Development of the Biosphere* (pp. 292-320). Oxford University Press, Oxford.

Jüdes, U. 1998. Human orientors: a system approach for transdisciplinary communication of sustainable development by using goal functions. In F. Müller and M. Leupelt (Eds.), *Eco Targets: Goal Functions and Orienters* (pp. 381-394). Springer, Berlin.

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications* 1:66-84.

Kay, J.J. 1993. On the nature of ecological integrity: some closing comments. In S. Woodley, J. Kay and G. Francis (Eds.), *Ecological Integrity and the Management of Ecosystems*. University of Waterloo and Canadian Park Service, Ottawa.

Krupa, B. 2002. On the number of experiments requires to find the causal structure of complex systems. *Journal of Theoretical Biology* 219: 257-267.

Li, B.L. 2000a. Fractal geometry applications in description and analysis of patch patterns and patch dynamics. *Ecological Modelling* 132: 33-50.

Li, B.L. 2000b. Why is the holistic approach becoming so important in landscape ecology? *Landscape and Urban Planning* 50: 27-41.

Li, B.L. 2001. Fuzzy statistical and modeling approach to ecological assessments. In M.E. Jensen and P.E. Bourgeron (Eds.), *A Guidebook for Integrated Ecological Assessments* (pp. 211-220). Springer-Verlag, New York.

Müller, F. 1992. Hierarchical approaches to ecosystem theory. *Ecological Modelling* 63: 215-242.

Müller, F. 1997. State-of-the-art in ecosystem theory. *Ecological Modelling* 100: 135-161.

Müller, F. 1998. Ableitung von integrativen Indikatoren der Funktionalität von Ökosystemen und Ökosystemkomplexen für die Beschreibung des Umweltzustandes im Rahmen der Umweltökonomischen Gesamtrechnungen (UGR). In STATISTISCHES BUNDESAMT (ed.), *Beiträge zu den Umweltökonomischen Gesamtrechnungen*, Bd. 2, Wiesbaden 1998.

Müller, F., Breckling, B., Bredemeier, M., Grimm, V., Malchow, H., Nielsen, S.N. and Reiche, E.W. 1997a. Ökosystemare Selbstorganisation. In O. Fränzle, F. Müller and Schröder W. (Eds.). *Handbuch der Ökosystemforschung*. Landsberg.

Müller, F., Breckling, B., Bredemeier, M., Grimm, V., Malchow, H., Nielsen, S.N. and Reiche, E.W. 1997b. Emergente Ökosystemeigenschaften. In O. Fränzle, F. Müller and Schröder W. (Eds.). *Handbuch der Ökosystemforschung*. Landsberg.

Norton, B.G. and Ulanowicz, R.E. 1992. Scale and biodiversity policy: a hierarchical approach. *Ambio* 21: 244-249.

O'Neill, R.V., De Angelis, D.L., Waide, J.B. and Allen, T.H.F. 1986. *A Hierarchical Concept of Ecosystems*. Princeton University Press, Princeton.

O'Neill, R.V., Johnson, A.R. and King, A.W. 1989. A hierarchical framework for the analysis of scale. *Landscape Ecology* 3: 193-206.

Øyehaug, L., Plahte, E. and Omholt, S.W. 2003. Targeted reduction of complex models with time scale hierarchy – a case study. *Mathematical Biosciences* 185: 123-152.

Rapport, D.J. 1989. What constitutes ecosystem health? *Perspectives in Biology and Medicine* 33: 120-132.

Wang, X., Wang, J. and Li, B.L 2001. Developing a sustainable development indicator via knowledge mining. *International Journal of Sustainable Development and World Ecology* 8: 119-126.

WCED (World Commission on Environment and Development) 1987. *Our Common Future*. Oxford University Press, Oxford.

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CHAPTER 4

EFFECTS OF ELEVATED ATMOSPHERIC CO_2 ON WETLAND SOILS

1. INTRODUCTION

Anthropogenic activities have increased the concentration of atmospheric CO_2 from about 280 parts per million (ppm) at the beginning of the industrial revolution to 369 ppm at the present time. Future estimates of atmospheric CO_2 concentration for the year 2050 range between 450 ppm and 600 ppm (Kattenburg *et al*. 1995). More than two decades of study on the effects of CO_2 enrichment have greatly improved our understanding of plant response such as net primary productivity, species abundance, community composition and soil respiration (root plus microbial respiration) in terrestrial ecosystems (Poorter 1993, Curtis and Wang 1998, Ball and Drake 1998, Mooney *et al*. 1999, Edwards and Norby 1999, Zak *et al*. 2000). In addition, the chemical and physical composition of plant material and decomposability of plant litter have drawn much attention (Cotrufo *et al*. 1994, Cotrufo and Ineson 1995, King *et al*. 1997)

Unlike the terrestrial ecosystem studies, however, relatively less effort has been made to elucidate possible effects of elevated CO_2 on wetland ecosystems. Although wetland ecosystems including peat-forming wetland cover only 2-6 % of global land surface (Gorham 1991), they play a pivotal role in global biogeochemical cycles. Firstly, peat accumulation in peatland ecosystems over thousands of years has resulted in a vast store of carbon of 455 Pg C (Gorham 1991, Van Breemen 1995, Adams and Faure 1998). This represents 20-30% of the world's pool of soil organic carbon and is comparable to the total carbon in the atmosphere as CO_2 (IPCC 1990). Secondly, wetlands are substantial sources of radiatively active trace gases such as CH_4 and N_2O (Freeman *et al*. 1993). For example, natural wetlands and rice paddies release about 40-50% of global emissions of CH_4, which is 25 times more radiatively active than CO_2 on a molar basis (Cicerone and Oremland 1988). As such, even small changes in net primary productivity or decomposition of soil organic matter by elevated CO_2 could significantly influence the balance of greenhouse gas flux between the atmosphere and biosphere. This would greatly influence the future trajectory of global warming (Mitchell *et al*. 2002). However, little is known about how C and N dynamics on wetland ecosystems will respond to elevated CO_2 conditions. In particular, below ground processes in wetland ecosystem are scarcely reported.

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The aim of this review is to organize existing knowledge about the effects of elevated CO_2 on wetland ecosystems. In particular, we would like to address the issue of how wetland ecosystems will respond to elevated CO_2 conditions and whether these responses may cause feedbacks to further global climate change.

2. SOIL RESPIRATION

Depending on species, the physiological stage of the plant, and environmental conditions, *ca.* 40-50% of the photosynthetically fixed carbon is transferred into the below-ground parts of plants (Helal and Sauerbeck 1984). It is also reported that 15% of the total fixed carbon is released from the roots, mainly by microbial and plant respiration (Whipps and Lynch 1983). The raised concentration of atmospheric CO_2 has increased biomass accumulation in roots of some vascular species and release of carbon from roots (Dakora and Drake 2000), leading to increased soil respiration (Zak *et al*. 1993, Ball and Drake *et al*. 1998). Kang *et al*. (2001) reported elevated CO_2 increased the concentration of pore water DOC and emissions of CO_2 on northern fen peat with *Juncus* and *Festuca* spp. Ball and Drake (1998) have examined changes in soil respiration in a Chesapeake Bay marsh ecosystem exposed to elevated CO_2. They showed that mean soil respiration rates under elevated CO_2 were significantly greater (15%) than that of under ambient CO_2 conditions. This result demonstrates that increase in root biomass during exposure to elevated CO_2 might stimulate microbial respiration, through increased root exudation (Ball and Drake 1998, Zak *et al*. 1993). Schrope *et al*. (1999) also found NEE (net ecosystem exchange of CO_2) values for rice plant grown in the CO_2 enriched treatment were higher than those for corresponding plants grown in the ambient CO_2 treatment. Ball and Drake (1998) showed that exposure of a tidal marsh ecosystem to elevated CO_2 resulted in an increased emission of green house gases from soil. These results suggest that the wetland ecosystem may not respond simply through a negative feedback (*i.e*. sequestering CO_2 as biomass permanently) for elevated CO_2 atmosphere, but may respond with a positive feedback by releasing more CO_2 into the atmosphere.

3. SOIL ENZYME ACTIVITIES

Elevated CO_2 concentration can affect soil enzyme activities in several ways. Moorhead and Linkin (1997) suggested that elevated CO_2 altered the soil enzyme characteristics in a tussock tundra ecosystem. They found significantly higher phosphatase activities at 680 μ mol/mol CO_2 on the surfaces of plants root, mycorrhizal surfaces, and in the shallowest organic horizons soil (Oe and Oi). This result implies that the increased primary productivity may induce higher rhizodeposition, resulting in general activation of microbes that are often carbon limited (Dhillion *et al*. 1996). However, an increased easily utilizable carbon supply (*e.g*., monosaccharides) to microbes may inhibit carbon-related enzyme production. This is supported by Moorhead and Linkin (1997), who found lowering of

endocellulase and exocellulase activities in the surface organic soil horizons exposed to elevated CO_2. However, Kang *et al*. (2001) reported no significant differences in the soil enzyme activities (acid phosphates, β -glucosidase and N-acetylglucosaminidase) in a northern fen bulk soil exposed to CO_2 enrichment. Only phosphatase showed a weakly significant lower activity under the elevated CO_2 conditions. It is suspected that actively growing vegetation under elevated CO_2 may compete against microbes for nutrients, resulting in general decrease in microbial activity (Freeman *et al*. 1998).

4. NUTRIENTS IN SOIL

The changes of nitrogen concentration in plant tissue by elevated CO_2 can affect decomposition and mineralization rates indirectly, altering soil N availability in plant-microbial system. Matamala and Drake (1999) showed total nitrogen concentration and exchangeable soil nitrogen (NH_4^+ + NO_3^-) contents were reduced by 29% and 55% in the upper 10 cm of the soil profile responded to eight years of elevated CO_2. However, elevated atmospheric CO_2 treatment did not alter the potential for N mineralization in soils containing *S. olney*. Other studies also have shown no changes in N mineralization rates and N availability under elevated CO_2 conditions (Ross *et al*. 1995). However, Zak *et al*. (1993) reported increased N mineralization under elevated CO_2, suggesting that increased microbial populations, which mediated by an increase in root exudates, would increase N availability for plants growing in elevated CO_2 atmospheres. This is in agreement with Dakora and Drake (2000) who found some fixed carbon was supplied to endophytic and belowground microbial process under elevated atmospheric CO_2 concentrations.

The rise in N_2 fixation with elevated CO_2 may be the major source of N for the ecosystem. Some studies have demonstrated a significant increase in N_2 fixation in terrestrial ecosystem (Hartwig *et al*. 1996, Zanetti *et al*. 1997). Dakora and Drake (2000) reported that elevated CO_2 stimulated greater N_2 fixation in stands of the C_3 sedge, *S. olneyi*. They also showed a significant increase in N_2 fixation in the marsh sediment exposed to elevated CO_2. Most intriguingly, however, though the rate of N_2 fixation under elevated CO_2 was increased, the total N content of plants was not increased.

Denitrification is one of the most important mechanisms returning N from terrestrial ecosystems to the atmosphere and is a major loss of N in most parts of a salt marsh ecosystem (Kaplan *et al*. 1979). Ineson *et al*. (1998) found higher N_2O-N, metabolite of denitrification, production beneath *Lolium perenne* growing under high N inputs and elevated CO_2. However, Matamala and Drake (1999) showed that potential denitrification rates were reduced in soil cores taken from *S. olneyi* community exposed to elevated CO_2.

A decrease in phosphorus contents as well as nitrogen content under elevated CO_2 has been reported (Jauhiainen *et al*. 1998, Van der Heijden *et al*. 2000). Jauhiainen *et al*. (1998) reported that nitrogen and phosphorus concentrations of *sphagnum* decreased with raised CO_2 concentrations. Van der Heijden *et al*. (2000) also

reported that total phosphorus content decreased significantly in *Sphagnum* capitula exposed to elevated CO_2.

5. METHANE FLUX

In recent years, a number of studies have addressed the potential changes in trace gas emissions from wetlands exposed to elevated CO_2 (Table 1). For example, Drake (1992) reported CO_2 enrichment stimulated methane emissions by 80% in a salt marsh containing sedge *S. olneyi*. Hutchin *et al*. (1995) also found a similar effect for mire peat and vegetation exposed CO_2 enrichment treatment. Allen *et al*. (1994) reported the same results in the combined condition of increased CO_2 and temperature. Wang and Adachi (1999) also provided evidence that elevated atmospheric CO_2 concentrations promote CH_4 production from flooded soils. Megonigal and Schlesinger (1997) who performed experiments with *Orontium aquaticum* reported CH_4 emissions increase by 136% under elevated CO_2.

However, Kang *et al*. (2001) found no significant differences for CH_4 emission on northern fen peat with *Juncus* and *Festuca* spp, although the mean value was higher under elevated CO_2 conditions. Saarnio *et al*. (1998) reported that the average release of CH_4 from *Sphagnum* samples exposed to the doubled concentration of CO_2 was significantly lower than that at ambient CO_2 at 9℃ and 4.5℃. Saarnio and Silvola (1999) showed the release of CH_4 for each temperature condition (1.5℃ - 14℃) was on average only 6-23% higher under CO_2-fertilised conditions. More recently Saarnio *et al*. (2000) found that elevated CO_2 (560ppm) increased CH_4 efflux by only 15-20% in boreal mires over two years using mini-FACE rings. The increase was clearly weaker than that in previous reports from temperate or subtropical areas (Dacey *et al*. 1994, Hutchin *et al*. 1995, Megonigal and Schlesinger 1997). In subtrophical and temperate conditions, CO_2 enrichment has been shown to increase CH_4 efflux during the growing season by about 80-150% (Hutchin *et al*. 1995, Megonigal and Schlesinger 1997, Dacey *et al*. 1994). These results imply the increase in CH_4 efflux correlated positive with peat temperature (Dacey *et al*. 1994, Hutchin *et al*. 1995). The majority of the known methanogenes are mesophilic with a temperature optima of about 35℃(Oremland 1988).

CO_2 enrichment may also lead to the attenuation of methane production due to increased delivery of oxygen to the rhizosphere. This is in agreement with Schrope *et al*. (1999) who reported methane emissions from rice grown in a sandy soil under doubled CO_2 were 4-45 times less. The increased root biomass due to elevated CO_2 may have more effectively aerated the soil, suppressing methane production.

However, Studies of natural and artificial wetlands have reported positive correlations between methane emission rates and plant aboveground biomass (Whiting and Chanton 1992, Whiting *et al*. 1991, Sass *et al*. 1990). Elevated CO_2 concentration might indirectly enhance CH_4 emissions from wetlands by increment in net primary production (Dacey *et al.* 1994, Guthrie 1986).

Table 1. Effects of elevated CO_2 on CH_4 fluxes in wetlands. Changes in CH_4 flux by elevated CO_2 are presented as (elevated-ambient)/ambient x 100. No significant differences between ambient CO_2 and elevated CO_2 treatments are indicated by the letter, NS.

Wetlands	*Species*	*CO_2 level (μ L /L)* *Ambient /elevated CO_2*	*Change of CH_4 flux (%)*	*Temp.*	*Facility*	*Reference*
Bog	Sphagnum	360 / 560	NS†	17 – 20℃	Glasshouse	Saarnio *et al.* (1998)
			(-) (P = 0.008)	9℃		
			(-) (P = 0.007)	4.5℃		
	Sedge	360 / 560	(+) (α = 0.05)	17 – 20℃	Glasshouse	
			NS	9℃		
			NS	4.5℃		
	Sphagnum	400-550 (night)/560 330-390 (day) / 560	+ 28 (P = 0.016)	Summer	Mini- FACE	Saarnio *et al.* (2000)
Emergent aquatic macrophyte	Orontium aquaticum	350 / 700	+ (P = 0.06)	ND	Glasshouse	Megonigal & Schlesinger (1997)
			+ 136 ($P \leq$ 0.01)	ND	Growth chamber	
Rice on sand	*Oryza sativa*	350 / 700	(-) ($P \leq$ 0.01)	ND	Temperature Gradient Greenhouse Tunnels	Schrope *et al.* (1999)
Marsh	*Scirpus olneyi*	345 / 690	+ 80 (F=0.012)	Summer	Open-top chamber	Dacey *et al.* (1994)
Fen	*Juncus* *Festuca* spp	350 / 700	+ 74.5 NS	ND	Glasshouse	Kang *et al.*, (2001)

† There was no significant differences in weekly CH_4 efflux from *Sphagnum* between ambient CO_2 and elevated CO_2 treatments except data after 49 weeks.

Uncertainties in the response of CH_4 emission from wetlands exposed to elevated CO_2 lie on the lack of long-term studies. In addition, changes in litter chemistry (Gorissen *et al*. 1995, Hirschel *et al*. 1997), nutrient deficiency (van de Geijin and van Veen 1993, Niklaus and Körner 1996), the height of water table (Roulet *et al*. 1992) or peatlands area (Gorham 1991) also might change the capability of methane emissions in wetland ecosystem under elevated CO_2 conditions.

6. CONCLUSION

As wetlands play a key role in global biogeochemical cycles, responses of wetlands to future global climatic changes are of great importance. Unlike the changes in temperature or water level, effects of elevated CO_2 are highly complex. Many studies have suggested that elevated CO_2 may increase greenhouse gas emission from wetlands and hence accelerate global warming. However, longer-term observations considering multiple interacting variables (*e.g.*, water level, nutrient availability, and temperature) will be needed if we are to improve our understanding of wetland systems.

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8. REFERENCES

Adams, J.M. and Faure, H. 1998. A new estimate of changing carbon storage on land since the last glacial maximum, based on global land ecosystem reconstruction. *Global and Planetary Change* 16: 3-24.

Allen, L.H. Jr., Albrecht, S.L., Colon, W. and Covell, S.A. 1994. Effects of carbon dioxide and temperature on methane emission of rice. *International Rice Research Notes* 19: 43.

Ball, A.S. and Drake, B.G. 1998. Stimulation of soil respiration by carbon dioxide enrichment of marsh vegetation. *Soil Biology and Biogeochemistry* 30: 1203-1205.

Cicerone, R.J. and Oremland, R.S. 1988. Biogeochemical aspects of atmospheric methane. *Global Biogeochemical Cycles* 2: 299-327.

Cotrufo, M.F., Ineson, P and Rowland, A.P. 1994. Decomposition of tree leaf litters grown under elevated CO_2: effect of litter quality. *Plant and Soil* 163: 121-130.

Cotrufo, M.F. and Ineson, P. 1995. Effects of enhanced atmospheric CO_2 and nutrient supply on the quality and subsequent decomposition of the fine roots of *Betula pendula* Roth. and *Picea sitchensis* (Bong.) Carr. *Plant and Soil* 170: 267-277.

Curtis, P.S. and Wang, X. 1998. A meta-analysis of elevated CO_2 effects on woody plant mass, form, and physiology. *Oecologia* 113: 299-313.

Dacey, V.W. H., Drake, B.G. and Klug, M.J. 1994. Stimulation of methane emission by carbon dioxide enrichment of marsh vegetation. *Nature* 370: 47-49.

Dakora, F.D. and Drake, B.G. 2000. Elevated CO_2 stimulates associative N_2 fixation in a C_3 plant of the Chesapeake Bay wetland. *Plant, Cell and Environment* 23: 943-953.

Dhillion, S.S., Roy, J. and Abrams, M. 1996. Assessing the impact of elevated CO_2 on soil microbial activity in a Mediterranean model ecosystem. *Plant and soil* 187: 333-342.

Drake, B.G. 1992. A field study of the effects of elevated CO_2 on ecosystem processes in a Chesapeake Bay wetland. *Australian Journal of Botany* 40: 579-595.

Edwards, N.T. and Norby, R.J. 1999. Below-ground respiratory response of sugar maple and red maple saplings to atmospheric CO_2 enrichment and elevated air temperature. *Plant and Soil* 206: 85-97.

Freeman, C., Baxter, R., Farrar, J.F., Jones, S.E., Plum, S., Ashendon, T.W. and Stirling, C. 1998. Could competition between plants and microbes regulate plant nutrition and atmospheric CO_2 concentrations? *The Science of the Total Environment* 220: 181-184.

Freeman, C., Lock, M.A. and Reynolds, B. 1993. Fluxes of CO_2, CH_4, and N_2O from a Welsh peatland following simulation of water table draw-down: potential feedback to climatic change. *Biogeochemistry* 19: 51-60.

Gorham, E. 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* 1: 182-195.

Gorissen, A., Van Ginkel, J.H., Keurentjes, J.J.B. and Van Veen, J.A. 1995. Grass root decomposition in retarded when grass has been grown under elevated CO_2. *Soil Biology and Biochemistry* 27: 117-120.

Guthrie, P.D. 1986. Biological methanogenesis and the CO_2 greenhouse effect. *Journal of Geophysical Research- Atmosphere* 91: 10847-10851.

Hartwig, U.A., Zanetti, S., Hebeisen T., Luscher, A., Frehner, M., Fischer, B.U., van Kessel, C., Hendrey, G.R., Blum, H. and Nosberger, J. 1996. Symbiotic nitrogen fixation: one key to understand the response of temperate grassland ecosystems to elevated CO_2? In C. Korner and F. Bazzae (Eds.), *Carbon dioxide, Populations, and Communities* (pp. 253-264). Academic Press, San Diego, CA.

Helal, H.M. and Sauerbeck, D.R. 1984. Influence of plant roots on C and P metabolism in soil. *Plant and Soil* 76: 175-182.

Hirschel, G., Korner, C.H. and Arnone, J.A. III. 1997. Will rising atmospheric CO_2 affect leaf litter quality and *in situ* decomposition rates in native plant communities? *Oecologia* 110: 387-392.

Hutchin, P.R., Press, M.C., Lee, J.A. and Ashenden, T.W. (1995). Elevated concentrations of CO_2 may double methane emissions from mires. *Global Change Biology* 1: 25-128.

Ineson, P., Coward, P.A. and Hartwig, U.A. 1998. Soil gas fluxes of N_2O, CH_4 and CO_2 beneath *Lolium perenne* under elevated CO_2: The Swiss free air carbon dioxide enrichment experiment. *Plant and Soil* 198: 89-95.

IPCC 1990. *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, Cambridge, UK.

Jauhiainen, J., Silvola, J. and Vasander, H. 1998. The effects of increased nitrogen deposition and CO_2 on *Sphagnum angustifolium* and *S. warnstorfii*. *Annales Botanici Fennici* 35: 247-256.

Kang, H.J., Freeman, C. and Ashendon, T.W. 2001. Effects of elevated CO_2 on fen peat biogeochemistry. *The science of the total environment* 279: 45-50.

Kaplan, W., Valiela, I. and Teal, J.M. 1979. Denitrification in a salt marsh ecosystem. *Limnology and Oceanography* 24: 726-734.

Kattenburg, A., Giorgi, F., Grassl, H., Meehl, G.A., Mitchell, J.B. F., Stouffer, R.J., Tokioka, T., Weaver, A.J., and Wigley, T.M.L. 1995. Climate models-projections of future climate. In J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenburg and K. Maskell (Eds.), *Intergovernmental Panel on Climate Change* (pp. 290-349). Cambridge University Press, New York.

King, J.S., Thomas, R.B. and Strain, B.R. 1997. Morphology and tissue quality of seedling root systems of *Pinus taeda* and *Pinus ponderosa* as affected by varying CO_2, temperature, and nitrogen. *Plant and Soil* 195: 107-119.

Matamala, R. and Drake, B.G. 1999. The influence of atmospheric CO_2 enrichment on plant-soil nitrogen interactions in a wetland plant community on the Chesapeake Bay. *Plant and Soil* 210: 93-101.

Megonigal, J.P. and Schlesinger, W.H. 1997. Enhanced CH_4 emissions from a wetland soil exposed to Elevated CO_2. *Biogeochemistry* 37: 77-88.

Mitchell, E.A.D., Buttler, A., Grosvernier P., Rydin, H., Siegenthaler, A., and Gobat, J-M. 2002. Contrasted effects of increased N and CO_2 supply on two keystone species in peatland restoration and implications for global change. *Ecology* 90: 529-533.

Mooney, H.A., Canadell, J., Chapin, F.S., Ehleringer, J., Körner, C., McMurtrie, R.E., Parton, W.J., Pitelka, L.F. and Schulze, E-D. 1999. Ecosystem physiology responses to global change. In B. Walker, W. Steffen, J. Canadell and J. Ingram (Eds.), *The terrestrial biosphere and global change* (pp. 141-189). Cambridge University Press, Cambridge, UK.

Moorhead, D.L. and Linkins, A.E. 1997. Elevated CO_2 alters belowground exoenzyme activities in tussock tundra. *Plant and Soil* 189: 321-329.

Niklaus, P.A. and Körner, C. 1996. Responses of soil microbiota of a late successional alpine grassland to long term CO_2 enrichment. *Plant and Soil* 184: 219-229.

Oremland, R.S. 1988. Biogeochemistry of methanogenic bacteria. In A.J.B. Zehnder (ed.), *Biology of Anaerobic Microorganisms* (pp. 641-706). Wiley, New York.

Poorter, H. 1993. Interspecific variation in the growth response of plants to an elevated ambient CO_2 concentration. *Vegetatio* 104/105: 77-97.

Ross, D.J., Tate, K.R. and Newton, P.C.D. 1995. Elevated CO_2 and temperature effects on soil carbon and nitrogen cycling in ryegrass/white clover turves of an Endoaquept soil. *Plant and Soil* 176: 37-49.

Roulet, N., Moore, T. and Lafleur, P. 1992. Northern fens: methane flux and climatic change. *Tellus* 44B: 100-105.

Saarnio, S. and Silvola, J. 1999. Effects of increased CO_2 and N on CH_4 efflux from a boreal mire: a growth chamber experiment. *Oecologia* 119: 349-356.

Saarnio, S., Alm, J., Martikainen, P.J. and Silvola, J. 1998. Effects of raised CO_2 on potential CH_4 production and oxidation in, and CH_4 emission from, a boreal mire. *Ecology* 86: 261-268.

Saarnio, S., Saarinen, T., vasander, H. and Silvola, J. 2000. A moderate increase in the annual CH_4 efflux by raised CO_2 or NH_4NO_3 supply in a boreal oligotrophic mire. *Global Change Biology* 6: 137-144.

Sass, R.L., Fisher, F.M., Harcombe, P.A. and Turner, F.T. (1990). Methane production and emission in a Texas rice field. *Global Biogeochemical Cycles* 4: 47-68.

Schrope, M.K., Chanton, J.P., Allen, L. H. and Baker, J.T. 1999. Effect of CO_2 enrichment and elevated temperature on methane emissions from rice, *Oryza sativa*. *Global Change Biology* 5: 587-599.

Van Breemen, N. 1995. How Sphagnum bogs down other plants. *Trends in Ecology and Evolution* 10: 270-275.

van de Geijn, S.C. and van Veen, J.A. 1993. Implications of increased carbon dioxide levels for carbon input and turnover in soils. *Vegetatio* 104-105: 283-292.

Van der Heijden, E., Verbeek, S.K. and Kuiper, P.J C. 2000. Elevated atmospheric CO_2 and increased nitrogen deposition: effects on C and N metabolism and growth of the peat moss *Sphagnum recurvum* P. Beauv. Var. mucronatum (Russ.) Warnst. *Global Change Biology* 6: 201-212.

Wang, B. and Adachi, K. 1999. Methane Production in a flooded soil in response to elevated atmospheric carbon dioxide concentrations. *Biology and Fertility of Soils* 29: 218-220.

Whipps, J.M. and Lynch, J.M. (1983). Substrate flow and utilization in the rhizosphere of cereals. *The New Phytologist* 95: 605-623.

Whiting, G.J. and Chanton, J. 1992. Plant-dependent CH_4 emission in a subarctic Canadian Fen. *Global Biogeochemical Cycles* 6: 225-231.

Whiting, G.J., Chanton, J., Bartlett, D. and Happell, J. 1991. Methane flux, net primary productivity and biomass relationships in a subtropical grassland community. *Journal of Geophysics Research* 96: 13067-13071.

Zak, D.R., Pregistzer, K.S., Curtis, P.S., Terri, J.A., Pogel, R. and Randiett, D.L. 1993. Elevated atmospheric CO_2 and feedback between carbon and nitrogen cycles. *Plant and Soil* 151: 105-117.

Zak, D.R., Pregitzer, K.S., King, J.S. and Holmes, W.E. 2000. Elevated atmospheric CO_2, fine roots and the response of soil microorganisms: a review and hypothesis. *The New Phytologists* 147: 201-222.

Zanetti, S., Hartwig, U.A., van Kessel, C., Luscher, A., Hebeisen, T., Frehner, M., Fischer, B.U., Hendrey, G.R., Blum, H. and Nosberger, J. 1997. Does nitrogen nutrition restrict the CO_2 response of fertile grassland lacking legumes? *Oecologia* 112: 17-25.

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CHAPTER 5

TOWARD PREDICTING EFFECTS OF FIRE ON VEGETATION DYNAMICS UNDER CHANGED CLIMATE SCHEME - LANDSCAPE SCALE MODELS

1. INTRODUCTION

More and More efforts are given to landscape scale models in ecological researches recently, for they are crucial in bridging the gap between broad scale generalization and fine scale measurements in global change studies. Disturbances, such as: fire, wind, drought, insect and disease, are hot topics of landscape scale models, for they are the main agents in creating patchiness to form heterogeneous landscape and shifting mosaics, which are considered to be typical at this scale. Fire, the most common disturbances in most terrestrial ecosystems, and with relative predictable regime (frequency, mean area, return interval) compare to other types of disturbances, is often chosen by researchers as example to show the importance of effects of disturbance on vegetation dynamics. It is now commonly accepted that fire disturbance may plays a major role in shaping and maintaining many terrestrial ecosystems. Models dealing with these ecosystems without considering fire disturbance are thought to be at lest inadequate. Many researchers further point out fire may play a more important role in the responses of vegetation to rapid climate change. Fire regime change may have more drastic effects on vegetation response then the effects of physiological change such as growth rate and mortality during the period of rapid climate change. Many influential research projects, such as IGBP, give high priority in developing an appropriate fire disturbance model.

However, it is not a easy task to predict fire effects on vegetation dynamics, because the relationships among weather, fire, and the dynamics of vegetation require an understanding of fine-grained details of fire ignition, fire spread, the patterns of vegetation and their response to fire, and the fast changing weather conditions imbedded in the long term-trends and potential shifts in climate. Additionally, the complexity of human influences and the uncertainty of their trends make the problem more difficult.

A surge of research reports on wild fires and their effects appeared on scientific literature beginning form 1970’s, and continue to be active. Most of these studies are

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based on theoretic analyses or empirical methods. They are inadequate to predict the behaviour of the complex system composed of fire, weather, and vegetation, but their results provide the foundation of and insight into building holistic model to deal with this complex system.

For strongly needed, and also for becoming more feasible from former research accumulation, many simulation models appeared recently to address this topic. We review selected models based on two considerations: firstly, to show the variety of methods they used. Secondly, to trace logical evolution of models, that may contribute to future model development. Then, by making some mechanistic analysis based the review of former models and our speculation, we propose a framework consisting of several sub-models, and discuss how to link them into a holistic one.

2. MODELS REVIEW

2.1. Models classified by ways dealing with fire disturbance

By referencing to Gardner's paper (Gardner 1999), we classify models into 5 categories base on the way they deal with fire disturbance: *theoretical models*, which are simple formulations designed to explore fundamental concepts such as critical threshold, fractal structures or self-organization (MacKay and Jan 1984, Bak *et al*. 1990, Malamud *et al.* 1998); *exploratory models*, which have similarity with theoretical ones, but are more complex and provide greater details concerning landscape effects (von Niessen 1988, Ratz 1995); *Probabilistic model,*; which developed as extension of cellular automata model to simulate fires in heterogeneous landscape [Clarke *et al*. 1994, Gardner *et al.* 1997]; *mechanistic models*, which are base on thermo-physics principles of fire behaviour (Rothermel 1972, Andrews *et al*. 1986, Vaconcelos 1992, Finney 1998); and *Statistic models*, which using estimated probability density function to simulate fire regimes (Johnson and von Wagner 1985, Baker *et al*. 1991, He and Mladennoff 1999).

Theoretical models: As defined before, theoretical models are extremely simple in assumption. So, its behaviour can be fully explored. Their spatial and temporal scales are often Arbitrary. These models have no intension to simulate real landscape, but intend to address common characters of fire prone system. Insightful principles or fundamental assumptions may be raised by them, or be explored further. We ecologists often ignored their roles, but they may take effect unconsciously on our model construction at the very beginning.

Models developed by Bak *et al*. (1990) and Malamud *et al*. (1998) provide 2 interesting examples. Bak's model use very simple assumption to model fire disturbance and forest "grow back", and find that as long as both fire disturbance exits and forest keep growing, the landscapes will constantly exist near critical threshold. Turbulence of fire regime is intrinsic of this system. Well, Malamud's model reveals the self-organized characteristic of forest fires. Fires number-area relation follows power law.

Exploratory models: Exploratory models are more complicated then theoretic models, and they begin to explore some aspects of real landscape problems, but still keep many aspects arbitrary. The assumption and results are more complicated and it's very difficult to fully explore system behaviour as done in theoretic models. More focus is also on real world problems. Exploratory models are the transition from theoretic model to real landscape models.

One example of exploratory model is the one developed by von Niessen (1988), this model is analogous to that of Bak', but use real spatial scale, and using double lattice to model surface fire and crown fire separately. Wind effect on fire spreading is also taken into consideration. The result shows critical threshold exists but the critical value varied considerably with assumption and parameters. Another example of exploratory model is the one developed by Ratz *et al*. (1994). It uses cellular automation method to explore effect of age-dependent forest flammability on spatial characteristic of forest fire. Results show that age-dependent flammability may cause more complex spatial patterns then age -constant flammability does. Large area fires are more likely to occur in this age-dependent flammability system.

Probabilistic models: These models are the descendants of cellular automation game. The behaviour of the system depends on the rules of neighbourhood interactions, and the rules are probabilistic. The characteristics of the system lie behind large number of stochastic evens. The objects of these models are real world landscapes, and are more realistic then former models. These models do very well in simulating fractal structure of wild fires and are much more computational efficient then mechanistic models. But they give unrealistic timing of fire spreading process and are unsuitable to predict fire intensity. These models have the potential to be used by fire ecologists, and have potential to reflect climate changes.

The model developed by Clarke *et al.* (1994) is a probabilistic model. This model uses diffusion limited aggregation (DLA) algorithm. Firelets move to neighbours according to their probabilities, which are affected by fuel load, wind, slope and fuel moisture etc. The intension of this model is to integrate itself to remote sensing monitoring software to predict real time fire spreading. The model has been validated by field data.

EMBYR, developed by Gardener *et al.* (1997) is another probabilistic model. The neighbourhood spreading probability is a function of fuel type, fuel moisture, wind, and slope etc. Spotting fires are also successfully integrated into this model. The main purpose of the model is to simulate large fires and their influences on heterogeneous landscapes. Results show fractal spatial structure and critical threshold exist in this system. This model was used to Yellowstone National Park and performs quiet well.

Mechanistic models: Mechanistic models are another type of models that are originally developed for fire control and management. Although they were developed relatively separate form ecological models, now, more and more ecologists begin to take the advantage of these models. A large body of studies has been built up in this area, but most of the rooted to the same origin: Rothermel model, an influential paper published by Rothermel at 1972. Because these models

have solid physics bases, they are the most successful models in simulating real fire behaviour, including realistic fire spreading processes and fire behaviour, which are week for other kinds of models. There are several advantages for these models to be used for modelling fire effects on vegetation under climate change schemes. Firstly, patchiness of fire intensity and hence patchy vegetation is very important for long-term vegetation succession, so mechanistic fire models should be very valuable for their strengths in predict fire intensity. Secondly, these models are rather sensitive to weather date, which may be important to reflect gradual climate changes. Thirdly, these models make better use of fuel load data, which may give a more realistic presentation of the interaction between fire regime and fuel dynamic. But many ecologists think there are great disadvantages of these models, for they need great quantity of detailed data and parameters, and their very complicated calculation, which make it infeasible for practical use. The simplification of mechanistic models and rapid improvement in computer capacities may provide new opportunity of ecologists to reconsider the potential to use these models.

Actually, there are already 2 models can be served as examples to be used for ecological studies: FIREMAP, a raster GIS based fire model developed by Vasconcelos, and FARSITE, a vector GIS based fire model developed by Finney (1998). FARSITE is already used to a famous fire ecological model: FIRE-BGC, which will be discussed later.

Statistic models: Another thread of fire models may comes form the idea of using fire history data. Statistical models have several advantages which may be very attractive to ecologist: they are the best way to incorporate historical fire regime data into model and should not be very unrealistic (other models could be!) in fire regime; and they are very computational efficient. But there are also some disadvantages too: spatial pattern, especially patchy characteristics of fire intensity is not obvious in these models; historic data usually didn't contain detailed information of fuel and weather condition, so it's not easy to establish relations among fire, fuel, and weather this way, and furthermore, statistics do not always exist for future weather scheme. So, if we look fire as a driving force to vegetation change, it is a very suitable way to use these models. If they should be used to consider interactions among climate, fire, and vegetation, these models are unsuitable.

The most influential work in statistical fire model may be attributed to Johnson and von Wagner. In their paper published in 1985, they use Weibull distribution model to estimate fire interval distribution, and further point out this kind of distribution is related to increased fire hazard of stand age. Negative exponential distribution is a special kind of Weibull distribution when fire hazard is age-independent.

DISPATCH model developed by Baker *et al.* (1991), and LANDIS model developed by He and Mladenoff (1999) both use statistical models. But they developed special methods to make their results spatial.

2.2. Models classified by ways dealing with vegetation succession

A large body of succession models has been developed for various purposes, and this is one of the most active areas in ecological research. We just focus on those used to model landscape dynamics with fire disturbances.

By tracing the way they deal with vegetation succession, we classify models into 5 categories: *Markov type models*, which predict landscape dynamic change using transition matrix based on Markov Stochastic process principle (Gardner *et al*. 1997); *GAP originated models*, which are derived from the most commonly discussed gap phase model to predict community succession on the basis of individual tree's performance (Miller and Urban 1999); *BGC type models,* Which are descendants of Forest-BGC, to model vegetation succession on the basis of plant physiology and C, N flow in ecosystems (Keane *et al*. 1996); *Vital attributes models*, which predict community succession base on species vital attributes (Moore and Noble 1990); and *community structure based models*, which deal with succession based on community structure dynamic (species composition, and age structure) (He and Mladenoff 1999, Gardner and Kou, unpublished).

Markov model: Markov model may be the most commonly used model in landscape ecology. It use transition matrix to predict mosaic shifting of landscape change. EMBYR, developed by Gardner *et al.* (1997), uses Markov model as its succession module. Transition matrixes of succession among succession stages, and before and after fires are estimated. The problem is this model contains very few details on the mechanism of fire effects and succession. We are trying to replace this module in EMBYR with another model named PSDL, which will be discussed later (Gardner and Kou, unpublished).

GAP originated models: GAP type of models may be the most widely discussed and validate model in ecological studies. They are very powerful in mechanistically modelling forest succession and climate change effects. To our goal of modelling fire effects in broad scale landscapes over long time range, they are strong in simulating vegetation response to climate change, in modelling fuel dynamic driving by plant inputs. For being individual based model, they are very computational intensive, and seem unlikely to be used to broad scale landscapes. There does exist an example to use GAP model to simulate fire effect on vegetation at landscape scale, which is the work done by Miller and Urban (1999), but their simulating area covers only 9 ha. Extending their model to larger area is extremely difficult.

BGC type models: Forest-BGC may be one of the most mechanistically based models in ecology. It explicitly simulates important physiological processes such as photosynthesis, respiration, transpiration, and material allocation among different parts of plant. It is mainly developed to calculate cycling of carbon, water, and nitrogen. These model uses "large tree" assumption makes it relatively computational efficient than GAP models when used to landscape scale, but it contain few details necessary for after fire succession. The difficulty to estimate parameter is another problem. FIRE-BGC is a model developed by Keane *et al.* (1996), which uses hierarchical spatial organization to keep the advantage of computational efficiency of Forest-BGC, while incorporating details provided by

GAP model. The main advantage of this model is its strength to dealing with fuel dynamic, which is critical for simulating interaction between vegetation and fire. The complexity of model structure and difficulty of parameter estimation may be the main concern to be widely used.

Vital attributes models: models of this type are based on the influential work done by Noble and Slatyer (1980), which uses plants' vital attributes to predict successional changes in disturbance prone communities. The most important character of these models is that they are extremely simple in calculation, and still keeps almost all the important process needed to predict the pathway of community succession in recurrent disturbance environment. The problems using these models to our purpose are their lacking suitable way to incorporate climate change effects; lacking suitable way to model spatial interactions, such as species invasion between adjacent landscape elements; and their incapability to model fuel dynamics, for not containing details of community biomass.

FATE model, produced by Moore and Noble (1990), is an example of vital attribute model used to landscape level. This model extended its function by explicitly considering forest stratification and by using age cohort concept to depict community structure. So, it contains more details of plants competition, which should be very important in after fire succession. This model uses plant function type as the basic taxonomic unit, and homogenous community as basic spatial unit. This model is much more powerful than the prototype, but it still share the common shortcomings of this type, if it is intended to be used to climate change issues.

Community structure based models: Models of this type deal with succession on the bases of knowledge of community structures. Species composition and their age structure are explicitly simulated. Age classes of each species (or plant function type) of the community are the basic entities in the models. Competition for light is considered important mechanism for after fire disturbance. These models have the advantage over GAP type models on their computational effectiveness to be used to large scaled landscapes, for they are not individual based. On the other hand, they are more detailed than vital attribute models, so that they contain many important processes, which are essential to the aim of this paper. This kind of models are rooted both from GAP type models and Vital attributes model, with careful consideration to reconcile the needs of details of important processes and the capacity (memory and speed) of currently available computers. They have somewhat similarity with BGC type of models in this aspect, but pay more attention to mechanism of community succession rather than bio-geo-chemical cycling of carbon, water, or other nutrition elements in community.

LANDIS model developed by He and Mladenoff (1999) is one of the most influential models of this kind. It uses grid data to represent spatial distribution and landscape level. Within each cell, community structure is depicted as 10 years interval age classes for each species, and the age classes are just traced of their present/absent. Competition effect is dealt with by using simple rules. Seed dispersal between landscape elements is modelled spatially explicit. This model has the ability

to model the effects of disturbances of several kinds (fire, wind, and forest harvest), and the disturbance regime is predefined statistically.

Another example of Community structure based model is PSDL developed by Gardner and Kou (unpublished). This model has some similarities with LANDIS: they both have grid base spatial representation; they both spatial explicitly model seed disposal; and they both use age classes as basic model entities. The difference is on that: PSDL explicitly model vertical structure of plant community; PSDL group plants into function types, and can include grass and shrubs, while LANDIS just deal with tree species; PSDL model depict plants age classes by their percentage of cover instead of present/absent; and competition is dealt with numerically.

We feel PSDL improved LANDIS in several aspects that will be very important for after fire succession. Evidences show that tree seedlings and grass/shrub interaction is very important in the early stage of the after fire succession, PSDL has the ability to deal with interaction of different life forms. PSDL uses plant cover, which have numerical relationship with biomass, and hence fuel production. So, it has the potential to model feedback between vegetation and fire based on fuel dynamics. We should say PSDL is basically developed to address the issues of climate-fire-vegetation interactions.

3. A PROPOSED MODEL STRUCTURE

To predict effects of fire on vegetation dynamics under changed climate scheme and at broad scale, we should know the behaviour of climate or weather, wildfire, and vegetation and their interactions. Some other factors such as topography, fuel load, soil condition are also necessary components.

We think that at least 8 sub-models are needed to make up a holistic model structure to address our problem: *GCM sub-model, weather generating sub-model, fire ignition sub-model, fire behaviour sub-model, direct fire effect sub-model, fuel accumulating sub-model, vegetation habitat sub-model,* and *vegetation succession sub-model,* although some of them can be combined. The following chart shows frame of the model structure (Figure 1).

GCM sub-model is used to predict long term trend of climate change at large spatial scale. Usually, our study area lies within a uniform area of the model products, so it is non-spatial at the scale we are interested. The time span could be hundreds or thousands of years, and the resolution is in years or more. Its role is just provides a background to Weather Generator sub-model. As we all know, GCM do not give precise prediction but possible paths climate changes may follow, so our model is bound to explore possible effects climate and fire may have on ecosystems.

Weather generator sub-model is constrained by results of GCM sub-model. It gives both daily weather data used by Succession sub-model and hourly data used by Fire ignition sub-model and fire behaviour sub-model. Monte Carlo statistic experimenting technique should be used to generate stochastic weather data with certain probabilistic distributions. A few existing models provide good examples in doing so (Gardner 1996, Skiles and Richardson 1998).

Topographic and soil type factor are used to generate habitat type map, witch is spatial variable but temporal constant. This map is input into succession sub-model as constrain.

Succession sub-model is the most difficult part. Climate change effect, data transfers from Weather generator; habitat type, data come from Habitat type sub-model; and fire effects, data from Fire effects sub-model, are inputs of this sub-model. Tree litter-fall and dead trees data, derived from this model, can be transferred to Fuel sub-model. We think population based landscape model is suitable.

Fuel dynamic sub-model accepts data from Succession sub-model and Weather generator sub-model. Dead fuel input and decay processes are simulated. Fire effects sub-model may calculate fuel consumed by fire, and is transferred to this sub-model.

Fire ignition sub-model and Fire behaviour sub-model accept hourly weather date from Weather generator sub-model, and fuel load data from Fuel dynamic sub-model. Fire effect sub-model accepts spatial distribution and intensity data, calculate fire effects on plant community and fuel consumption. Effects of fire to plant community include: plant death, plant resprouting, seed survival, and seed bank release caused by fire.

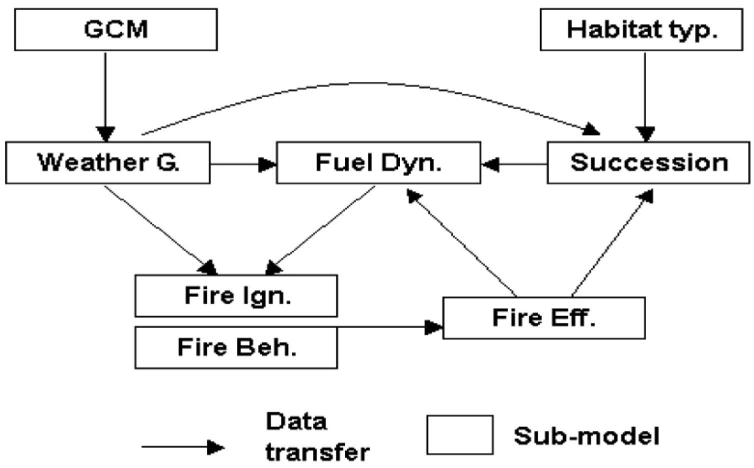

Figure 1. The structure of a holistic fire ecology model

4. CONCLUSION

Fire ecology models are developed rapidly recently, for they are very needy by ecosystem level researches and management, and also by global change researches.

The variety of purposes and methods are great. We find to classify models by two main line: by way dealing with fire disturbance and by way dealing with succession, is appropriate. Different types of models are developed to address their own problems and have their advantages, and also with limitations. No one single model can replace others currently. Models evolution shows we have got the opportunity to make a holistic model structure to predict effects of fire on vegetation dynamics under changed climate scheme at landscape level. We can see the hope, but long way still lies before us, when this holistic model can be fully developed.

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6. REFERENCES

Andrews P.L. 1986. *BEHAVE: fire behavior and fuel modeling system-BURN subsystem.* Part 1, SUDA, Forest service, General Technical Report INT-194

Bak, P., Chen, K. and Tang, C. 1990. A forest fire model and some thoughs on turbulence. *Physics A*, 147: 297-300

Baker, W.L., Egbert, S.L. and Frazier, G.F. 1991. A spatial model for studying the effects of climate change on the structure of landscape subject to large disturbances. *Ecol. Model*. 56: 109-125.

Clarke, K.C., Brass, J.A. and Riggan, P.J. 1994. A cellular automation model of wildfire propagation and extinction. *Photogrammetric Engineering and Remote Sensing* 60: 1355-1367

Finney, M.A. 1998. *FARSITE: Fire area simulation-model development and evaluation.* USDA Forest Service, RMRS-RP-4.

Gardner, R.H., Hargrove, W.W, Turner, M.G. and Romme, W.H. 1997. Climate change, disturbance and landscape dynamics. In R.H. Gardner, W.W. Hargrove, M.G. Turner and W.H. Romme (Eds.), *Global Change and Terrestrial Ecosystems* (pp. 114-172). IGBP series No. 2, Cambridge University Press, Cambridge.

Gardner, R.H., W.W, Romme, W.H. and Turner, M.G. 1999. Predict forest fire effects at landscape scales, In R.H. Gardner, W.W, Romme, W.H. and M.G. Turner (Eds.), *Spatial modeling of forest change* (pp. 163-185). Cambridge University Press, Cambridge.

Gardner, R.H., and Kou, X.J., PSDL: a model on predicting succession in disturbed landscapes, unpublished.

He, H.S., Mladenoff, D.J. and Boeder, J. 1999. An object-oriented forest landscape model and its representation of tree species, *Ecol. Model.* 119: 1-19.

Johnson, E.A. and van Wagner, C.E. 1985. The theory and use of two fire history models, *Canadian Journal of Forest Research* 15: 214-220.

Keane R.E., Morgan, P. and Running, S.W., *FIRE-BGC – A mechanistic ecological process model for simulating fire succession on coniferous forest landscape of Northern Rocky Mountains*, Intermountain Research Station Research Paper INT-RP-484.

MacKay, G. and Jan, N. 1984. Forest fires as critical phenomena, *Journal of Physics Letters A: Mathematics general* 17: 757-760.

Malamud, B.D., Morein, G.M. and Turcotte, D.L. 1998. Forest fires: an example of self-organizes critical behavior. *Science* 281: 1840-1841.

Miller, C. and Urban, D.L. 1999. A model of surface fire, climate and forest pattern in the Sierra Nevada, California, *Ecol. Model.* 114: 113-135.

Moore, A.D. and Noble, I.R. 1990. An individualistic model of vegetation stand Dynamics, *Journal of Environment Management* 31: 61-81.

Noble, I.R. and Slatyer, R.O. 1980. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances, *Vegetatio* 43: 5-21.

Ratz, A. 1995. Long-term spatial patterns created by fire: a model oriented towards boreal forests, *International Journal of Wildland Fire* 5: 25-34.

Rothermel, R.C. 1972. *A mathematical model for predicting fire spread in wild land fuels*, USDA Forest Service, IFRES-RP, INT-115.

Skiles, J.W. and Richardson, C.W. 1998. A stochastic weather generator model for Alaska, *Ecol. Model.* 110: 211-232.

Vaconcelos, M.J. and Guertin, D.P. 1992. FIREMAP-simulation of fire growth with a geographic information system, *International Journal of Wildland Fire* 2: 87-96.

von Niessen, W. and Blumen, A. 1988. Dynamic simulation of forest fires, *Canadian Journal of Forest Research* 18: 805-812.

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KANEYUKI NAKANE & HENRY L. GHOLZ

CHAPTER 6

PARTITIONING CARBON FLUXES WITHIN FOREST STAND BENEATH FLUX TOWER, METHODOLOGY AND APPLICATION

1. INTRODUCTION

Emissions of carbon dioxide (CO_2) from fossil fuel combustion and total anthropogenic emissions have been increasing by around 6.3 and 8.0 Gt C yr^{-1}, respectively (IPCC 1996), of which 3 Gt C year^{-1} has been explicitly linked to 'uptake by Northern Hemisphere forest regrowth' and to additional terrestrial sinks resulting from the combination of CO_2 fertilization, nitrogen deposition, and increasing temperature indirect effects. However, little scientific evidence for the 'additional terrestrial sinks' has yet been shown to confirm this, except for relatively short-term results from CO_2 enrichment experiments. The Kyoto Protocol was adopted in 1997, requesting that developed countries reduce their total CO_2 emissions by 2008-2012 to 92-95% of the level in 1990, taking the CO_2 balance of their forest ecosystems into consideration. This has lead to greatly increased attempts to measure directly the fluxes of CO_2 between the atmosphere and forest ecosystems. The main approach has been to use eddy covariance from towers above forest canopies to quantitatively evaluate the net ecosystem exchange of carbon dioxide over short periods (NEE). During the last five years many CO_2 flux towers have been built worldwide (ref. FluxNet: AmeriFlux, CarboEuro, AsiaFlux, etc.). Based on the tower data collected by the CarboEuro program, Valentini *et al.* (2000) suggested that most of the 30 forest stands monitored to date function as sinks for atmospheric CO_2, with the rate of increase rising from northern (boreal) to southern (warm-temperate) forests. Malhi *et al.* (1999) indicated that the magnitude of net carbon balance for tropical forest stands depends strongly on their biomass or net primary productivity. However, it is still not clear what suite of mechanisms in forest ecosystems collectively function to create a sink for carbon or where in any particular forest this occurs. Young forest stands generally function as carbon sinks, due to their positive increment in tree and litter biomass, and in some cases soil carbon. In this case, CO_2 fertilization, nitrogen deposition, or human fertilization and other cultivation generally greatly increases the magnitude of the sink. Saigusa *et al.* (2002) and Goulden *et al.* (1996) found that variation in weather conditions

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(precipitation, temperature and radiation) could account for much of the annual fluctuation in annual NEE (or net ecosystem production, NEP), based on long-term tower data over cool-temperate forests in central Japan and the northeastern U.S., respectively. However, few such long-term studies exist in the world.

One approach to resolution is to measure simultaneously the component carbon fluxes within ecosystems (e.g., CO_2 fluxes of soil, root or stem respiration and photosynthesis), because the balance of CO_2 fluxes at the tower is the net result of these fluxes (i.e., the balance between net CO_2 assimilation by vegetation and the mineralization of carbon from soil organic matter). For example, Jarvis *et al.* (1997) attempted to do this beneath a tower at a boreal forest in Canada, although they found that the data could not be scaled up to the stand level.

On the other hand, tower data evaluates NEE only around the tower, not over whole forests or regions. The BOREAS project tried to scale up the tower data to landscape and regional levels, using aircraft-based measurements around towers (Desjardins *et al.* 1997), finding good correlation between tower and aircraft data. However, in highly disturbed or fragmented landscapes, as is the situation over much of the earth and certainly throughout most of the U.S., Europe and southeast Asia and the Pacific, the question of how representative are single-tower flux measurements remains a serious limitation to their interpretation and extrapolation.

The methodology of choice for making continuous measurements of carbon flux above forest canopies has become eddy covariance. However, the continuous measurement of component fluxes within forest stands, i.e. beneath towers, has not been developed to the same degree. In this chapter, we explore the carbon balance of forests based on a series of papers presented at the symposium entitled "Partitioning carbon fluxes within forest stand beneath flux tower" at the 8th INTECOL held in Seoul in August 2002. Focus of the papers involved both the exploration of new methods and case studies within an overall context of scaling information first to the ecosystem, and then to the landscape.

2．METHODOLOGY FOR MEASUREMENT OF CARBON FLUXES WITHIN FOREST STANDS

2.1. Soil respiration (Myeong Hui Yim, Graduate School of Biosphere Sciences, Hiroshima University, Higashi-Hiroshima 739-8521, Japan)

CO_2 efflux from the soil surface to the atmosphere results from biological CO_2 production in the soil (mainly from the respiration of plant roots and soil organisms) and the transport of CO_2 through and out of the soil. Soil respiration is second only to gross photosynthesis in forest carbon budgets and is one of the key components in the carbon cycle of terrestrial ecosystems (Kira 1976, Raich and Schlesinger 1992). Also, soil respiration provides a useful index for the mineralization rate of organic matter and the activity of heterotrophic metabolism in soils (Ewel *et al.* 1987a, b). Many studies on the methodology for measuring soil respiration have been conducted. However, soil respiration is difficult to measure accurately due to the

uncertainty associated with the various methods, large inherent spatial and temporal variability, many environmental factors that may affect it variously in different locations, and so on (Norman *et al.* 1997). Several methods for measuring soil respiration have been developed, each with its own strengths and weaknesses. There is no standard or reference for determining the accuracy of any one of these methods (Nakayama 1990). Therefore, methodological differences among investigators can become the major source of uncertainty in estimating the carbon cycle at the forest and global levels (Jensen *et al.* 1996).

To date, the most commonly used method to measure soil respiration has been the static alkali absorption method (AA method) based upon absorption of CO_2 by alkali in solid or solution form. This method has the advantage of integrating the efflux over time (24 hours) and the capacity for easy measurement at many points. However, there is evidence that this method underestimates soil respiration, especially at high rates (Ewel *et al.* 1987, Nay *et al.* 1994, Haynes and Gower 1995, Jensen *et al.* 1996), and therefore global estimates of soil respiration largely based on it may be too low. Even so, it is likely that the AA method modified by Kirita (1971), in which the surface area of alkali solution is increased by the use of an alkali-soaked sponge disc, could enable better efficiency of CO_2 absorption at high efflux rates.

The dynamic closed chamber method (DC method), which calculates soil respiration using the rates of increase of CO_2 concentration in a closed chamber, is often regarded as superior to the AA method (Rochette *et al.* 1992, Norman *et al.* 1992), because the chamber has little influence on microclimatic variables and CO_2 concentration as measurements are made over relatively short periods. Several different types of apparatus have been developed, and commercially made chambers are now available. In fact, the LI-6200 or its revised (LI-6400) system (LI-COR, Lincoln, NE, USA) is now commonly used as a standard DC system for comparison and is considered to be relatively precise.

The open flow chamber system (OF method) is comprised of one reference and one sample line, an IRGA operating in absolute mode, and a data logger, and is most suitable for continuous measurement of soil respiration over the forest floor. The reference and sample lines are pneumatically independent of each other, ensuring a continuously stable flow rate through the lines and reducing the time taken to attain a steady level of CO_2 output; complete measurements of one sample can be made within a few minutes. In this case, ambient air enters the chamber at an appropriate flow rate and two-way solenoid valves allow alternate switching of the sample air from the chamber and reference air from the atmosphere. It is possible to continuously measure soil respiration for intervals of less than one or two hours to over a month or year using this method, even with multiple chambers.

2.1.1 Evaluation of the accuracy of DC and OF methods

Numerous field and laboratory studies have compared methodologies for measuring soil respiration, and the accuracy and precision of them have been long debated in the literature (Nay and Bormann 2000). Nakayama (1990) suggested that

all methods must be checked against a standard reference system of known flux to determine the best practical field procedure for estimating soil respiration. The standard reference system could be a container filled with inert silica sand or with soil of known composition and where known CO_2 concentration can be maintained at the bottom of the soil column. Consequently the CO_2 flux for the system could be calculated based on established diffusion equations.

Yim (2003) attempted to evaluate the absolute accuracy of the OF method, comparing it with known effluxes from the surface of a simulated soil. Yim tested OF and closed DC (LI-6400 system) methods. The reference method for determining the known flux of CO_2 from the laboratory apparatus was based on independent measurements of soil CO_2 diffusivity and the CO_2 concentration gradient, and the use of Fick's law of diffusion (Nay *et al.* 1994). In this case, the DC method of LI-6200 system consistently underestimated by 15% the reference method estimations of Nay *et al.* and was 10-24% (average of 15%) lower in the field than when the newer LI-6400 system was used (Yim 2003). The significantly different results of the two DC systems for measuring soil respiration may result from systematical differences among the chambers. The main differences between the systems, besides the measuring chamber volume and IRGA airflow, are the system of ventilation within the chambers and the system of pressure equilibration between air inside and outside the chamber (Le Dantec *et al.* 1999). In the LI-6000-09 chamber of LI-6200 system and the LI-6400-09 chamber of LI-6400 system, the pressure difference is negligible by virtue of a pressure relief vent tube, which keeps the pressure in chamber headspace in equilibration with the atmosphere. Air is withdrawn at the top of the chamber, passes through the IRGA, and reenters the chamber at a manifold ring at the bottom of the chamber. But only the LI-6400-09 chamber mixes air in the chamber headspace during the actual measurements, using the analyzer's mixing fan. The LI-6400-09 chamber system is considered to be effective in minimizing chamber-induced perturbations in the soil-gas concentration gradient and the pressure difference between the chamber headspace and the atmosphere. The LI-6400 system gave results similar to the calculated reference effluxes (Yim 2003, Fig. 1).

Open flow systems have a continuous stream of air passing through the chamber so that the difference between CO_2 concentrations entering and exiting the chamber, the gas flow rate, and enclosed soil surface area are used to calculate fluxes. Pressure anomalies caused by the flowing gas have made this method difficult to use reliably (Kanemasu *et al.* 1974). Negative chamber pressure differential cause high concentration soil air to sucked into the chamber, and therefore overestimate soil respiration, whereas positive pressure differentials suppress the undisturbed CO_2 efflux from the soil.

Fang and Moncrieff (1996) pointed out that this method fails to give a reasonable estimate of soil respiration when the magnitude of negative pressure is greater than –0.5 Pa. A pressure difference within ±0.2 Pa was recommended for getting reliable estimates of soil respiration rate using a dynamic chamber. Several approaches have been suggested to minimize pressure differences, such as simultaneously blowing and drawing air through the chamber (Fang and Moncrieff 1996), and the use of

very large air inlet apertures (Rayment and Jarvis 1997). The OF system employed by Yim (2003) simultaneously blows and draws air through the chamber to maintain the same air flow at the inlet and the outlet of chamber.

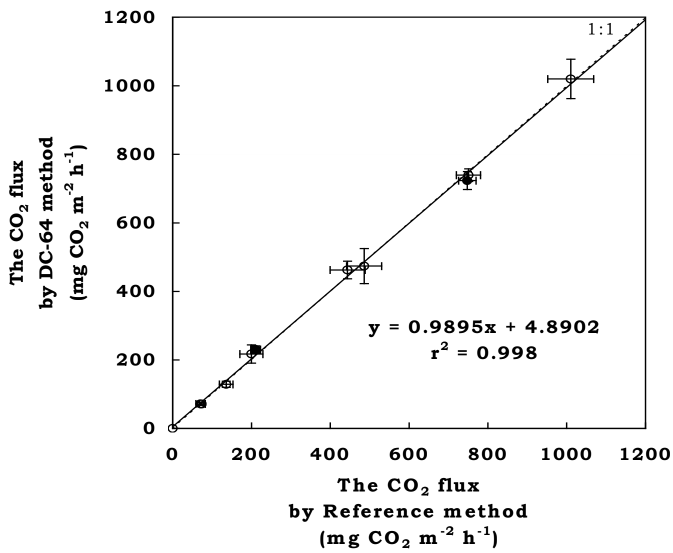

Figure 1. Comparison of the DC-64 method to the reference method calculated by Fick's Law (from Yim 2003). Each point represents a daily mean CO_2 flux (●, significant difference between the two methods, t-test, $P<0.05$). Error bars indicate standard deviation.

Yet Yim found that even when both flow meters at the inlet and the outlet of chambers were maintained at nearly the same rates, the flux values obtained by the OF method were highly sensitive to flow rate (Fig. 2). Significantly larger biases resulted from small errors (as small as 0.1 L min^{-1}) in determining flow rate. This suggests that flow rates should be changed according to the soil respiration rate, e.g. 0.6 L $350m^{-2}$ min^{-1} for CO_2 flux rates below 100 mg CO_2 m^{-2} h^{-1}, 1.0~1.2 L $350m^{-2}min^{-1}$ for rates ranging 200~500 mg CO_2 m^{-2} h^{-1}, and 1.4 L $350m^{-2}$ min^{-1} for rates ranging 500~800 mg CO_2 m^{-2} h^{-1}.

Fang and Moncrieff (1998) suggested that a possible explanation for the increase of measured CO_2 efflux with flow rate is that the increasing pressure difference is associated with the flow rate, but not the flow rate itself, and when air is blown and drawn simultaneously through a chamber, a higher flow rate will cause a larger pressure fluctuation. They also reported that the influence of pressure difference is related to the type of soil measured and that pressure differences cause more serious

over- or underestimation of soil respiration rates in soils that have a high respiratory capacity and large porosity.

Therefore, the changeable response of the measured CO_2 efflux to the flow rate through the chamber may also be caused by the pressure difference. Thus for continuous use of the OF system, a changeable flow rate system that responds to the

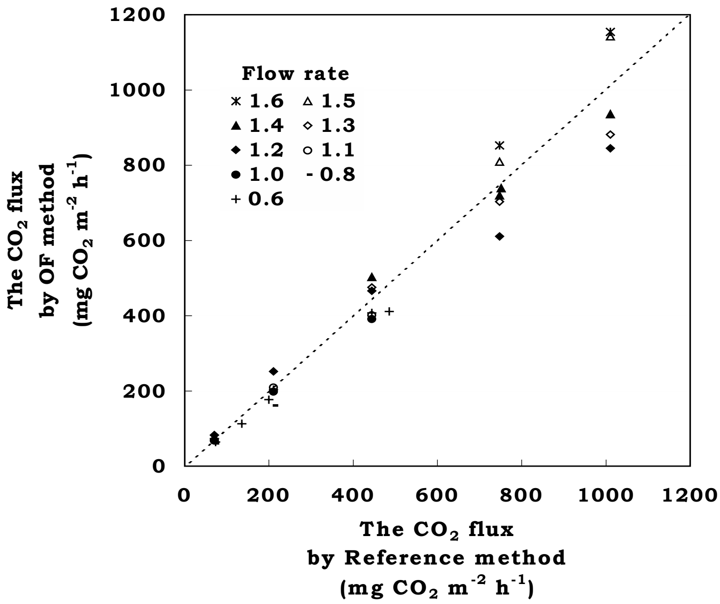

Figure 2. Effects of the air flow rate (L min^{-1}) through the OF chamber on the measured CO_2 flux by the OF method (from Yim 2003).

rate of soil respiration may be required. In addition, the chamber cover of an OF system needs to be opened during non-measurement periods to maintain air and soil conditions in the chamber the same as in the environment (Mizuguchi *et al.* 2003).

2.1.2 Spatial variability of soil respiration: estimation of the number of sampling points required

Soil respiration has a high spatial variability, so that a large number of sampling points is required to estimate a representative value. However, this is practically difficult when using the chamber methods that are commonly employed under field conditions. Many studies have estimated annual ecosystem soil respiration using 10 or fewer sampling points. Moreover, these studies have usually not used any specific plan for determining the spatial variability of soil respiration within the forest. Consequently, these estimates may be in error.

The variability of soil respiration within an ecosystem can be described by the coefficient of variation (CV), and the number of sampling points required to estimate a statistically significant mean soil respiration rate can be obtained using the CV value. However, it is difficult to compare the magnitude of spatial variability of soil respiration among different studies due to differences in the sizes of the experimental plots and the numbers of sampling points (Fang and Moncrieff 1998). Also, when the number of sampling points required is estimated from soil respiration data obtained from a few sampling points, the statistical significance of the estimate will be weak.

Yim (2003) determined the spatial variability of soil respiration and the number of sampling points required to get a representative value of soil respiration within an ecosystem, using 50 sampling points for the static alkali absorption chambers (AA method) within a 30m×30m plot in a 40-year-old larch (*Larix kaempferi*) plantation located on Tomakomai Flux Tower Research Site, Hokkaido, Japan. Yim found that, based on repeated measurement of soil respiration (mean±SD, CV: 776±201 mgCO_2 $m^{-2}h^{-1}$, 26%; 797±228 mg CO_2 $m^{-2}h^{-1}$, 29%), the average number of sampling points required to estimate the mean soil respiration in this experimental plot to within 10% and 20% of its actual value at the 95% probability level, were 30 and 8, respectively. Soil respiration is known to strongly depend on soil temperature and soil moisture content. However these two factors did not contribute to the spatial variability in this study (Yim 2003). These relationships suggest that soil temperature and moisture content more strongly influence the temporal variability than the spatial variability of soil respiration.

2.2. Root respiration (Mi Sun Lee, National Institute of Environmental Studies, Tsukuba 305-8506, Japan)

NEP of forest ecosystems is the balance between net primary production (NPP) of vegetation and heterotrophic respiration of soil. Respiration due to soil heterotrophs (fauna, bacteria and fungi) is the difference between total soil respiration and the activity of autotrophic roots and associated rhizosphere organisms (Edwards and Harris 1977). Precise assessment of these components is important for quantifying NEP. Although total and heterotrophic respiration has received considerable attention in recent decades, much less is known about the contribution of root respiration to total soil respiration. The contribution of each component needs to be understood in order that the implications of environmental change for soil carbon cycling and sequestration can be evaluated (Hanson *et al.* 2000).

The contribution of root respiration to total soil respiration is difficult to determine, as reflected by the wide range of published estimates for forest soils (10%–90%: Behera *et al.* 1990, Bowden *et al.* 1993, Coleman 1973, Ewel *et al.* 1987b, Edwards 1991, Nakane *et al.* 1996, Thierron and Laudelout 1996, Hanson *et al.* 2000, Ohashi *et al.* 2000). Although some of this variability reflects differences among types of ecosystems, a considerable proportion of it probably originates from

the variety of measurement techniques used, each with a unique set of limitations (Rochette *et al.* 1999). Methods for separating root respiration from total soil respiration have been reviewed by Singh and Gupta (1977) and Hanson *et al.* (2000) in detail.

The direct measurement of root respiration by digging up roots with soil may result in a rate significantly different from that in nature (Nakane *et al.* 1983). Attempts to measure root respiration rates by comparing clear-cut and non-cut stands by observing trends in soil respiration (Nakane *et al.* 1983, Nakane *et al.* 1996) are not widely applicable for logistical reasons. However, the trenching method of measuring root respiration is relatively simple, and its use is common in forest ecosystems (Rochette *et al.* 1999, Hanson *et al.* 2000). In this method, roots existing in a given area are severed at the plot boundary but not removed. The root respiration rate is estimated from the difference in soil respiration rates between the trenched plot and a control plot. However, one of the biggest concerns is the influence of residual decomposing roots left in the trenched plots and their contribution to soil respiration. An additional challenge is the potential seasonality of root activity, which may cause the contribution of root respiration to total soil respiration to change seasonally. Studies have shown differences between the growing season and the dormant season in the contribution of root respiration to total soil respiration (Edwards 1991, Rochette and Flanagan 1997). However, little information is available on the contribution of root respiration to total soil respiration during the growing season.

Lee *et al.* (2003) carried out continuous measurements of root respiration rate by a trenching method in a cool-temperate deciduous broad-leaved forest in central Japan. Soil respiration rates in four pairs of trenched and control plots were measured throughout the years using an OF technique. Carbon emission due to the decomposition of the residual roots in the trenched plots was estimated by a root bag method. The soil respiration rates in the control plot increased from May (240–320 mg CO_2 m^{-2} h^{-1}) to August (840–1150 mg CO_2 m^{-2} h^{-1}) and then decreased during autumn (200–650 mg CO_2 m^{-2} h^{-1}). Soil respiration rates in the trenched plot showed a similar pattern of seasonal change, but the rates were lower than in the control plot except during the 2 months following the trenching (Fig. 3). Root and heterotrophic respiration rates were estimated from total soil respiration rates in the control and trenched plots, and decomposition of dead roots in the trenched plots. Lee *et al.* estimated that the contribution of root respiration to total soil respiration in the growing season ranged from 27% to 71%. There was a significant relationship between heterotrophic respiration rate and soil temperature, whereas the root respiration rate had no significant correlation with soil temperature (Fig. 4). The results suggest that the factors controlling the seasonal change of respiration differ between the two components of total soil respiration (root and heterotrophic respirations).

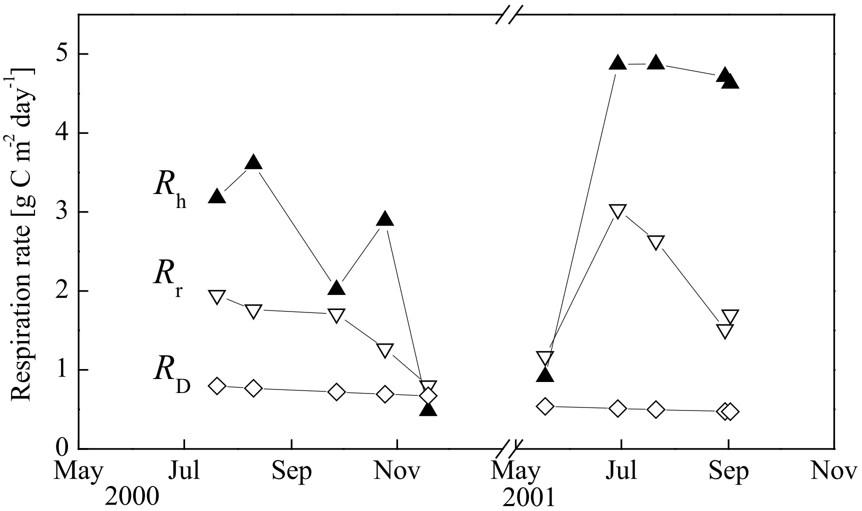

Figure 3. Seasonal changes in heterotrophic (R_h), root (R_r) and root decomposition rates (R_D) (Lee et al. 2003).

2.3 Stem respiration (Myung Hyun Kim, Graduate School of Biosphere Sciences, Hiroshima University, Higashi-Hiroshima 739-8521, Japan)

Respiration of tree stems has been measured much less than respiration of foliage or roots (or soil). However, for the viewpoint of the carbon balance of an ecosystem over a year or more, stem respiration may be an important component, because stem biomass increases continuously with stand development and account for the largest part of the forest biomass. Sprugel and Benecke (1991) suggested that woody-tissue respiration rates in the growing season are typically substantially greater than foliar respiration rates. Also, Damesin *et al*. (2002) reported that stem and branch respiration had been measured as about one third of total carbon loss by ecosystem respiration for a beech (*Fagus sylvatica*) forest. Many researchers have measured respiration of stems and branches using cut sections in the laboratory under controlled conditions (Yoda *et al*. 1965, Negisi 1974, Kinerson 1975, Mori and Hagihara 1988) or using young trees in the field (Ogawa *et al*. 1985, Yokota and Hagihara 1995, Maier *et al*. 1998, Xu *et al*. 2001). The excision method does not allow repeated measurements on the same sample and usually exhibits much higher rates than intact sections, due to wound respiration (Sprugel and Benecke 1991).

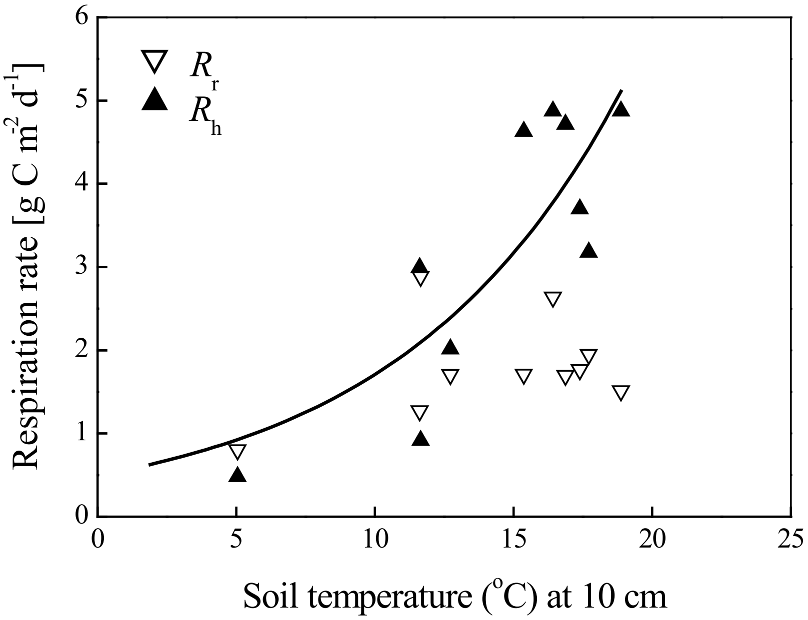

Figure 4. Relationships between root (R_r) and heterotrophic (R_h) respiration and soil temperature. The line was fitted with an exponential function for R_h (Lee et al. 2003).

The measurement of stem respiration using young trees may induce overestimates because the proportion of active tissue in younger trees is higher than in older trees (Maier *et al*. 1998). Another method for stem respiration measurement is the closed chamber method (Stockfors and Linder 1998), where a chamber is attached to the living stem in the field. This method is difficult to use continuously, and may underestimate when the CO_2 concentration becomes too high within the chamber, especially in the growing season with a high metabolic activity.

Because of these problems, most recent studies have been conducted using living and mature trees in the field with open flow chamber systems (Damesin *et al*. 2002, Edwards and Hanson 1996, Ryan *et al*. 1995, Lavigne *et al*. 1996). However, studies have been conducted only at special periods within a year (non-continuous measurement) and for dominant species in the study sites. The data may not represent stem respiration over a year and over the whole forest stand, because plant respiration is sensitive to changes in temperature, CO_2 or protein concentration, and

to water stress and atmospheric pollutants (Ryan 1991), and because respiration varies among species (Ryan *et al*. 1995, Negisi 1982, Edwards and Hanson 1996, Ryan *et al*. 1994). On the other hand, continuous data are needed to analyze the mechanisms of ecosystem carbon balance. Therefore, it is important to develop continuous measurement systems.

It is well known that stem respiration increases exponentially with temperature, but the exact nature of this relationship is not clear. Several authors (Lavigne *et al*. 1996, Ryan *et al*. 1995, Stockfors and Linder 1998, Linder and Troeng 1981) reported that stem respiration was more closely correlated to air or stem temperatures observed precedently rather than to current air or stem temperatures. The mechanism for a lag time between the response of stem respiration and the temperature is not clear, again supporting simultaneous and continuous measurements of both respiration rate and climate factors.

In order to address this for a Japanese red pine (*Pinus densiflora*) forest ecosystem in Higashi-Hiroshima, west Japan, Kim and Nakane (*in prep*.) used an OF system to continuously measure stem respiration of 15 samples at one hour intervals throughout a year in the field (Fig. 5).

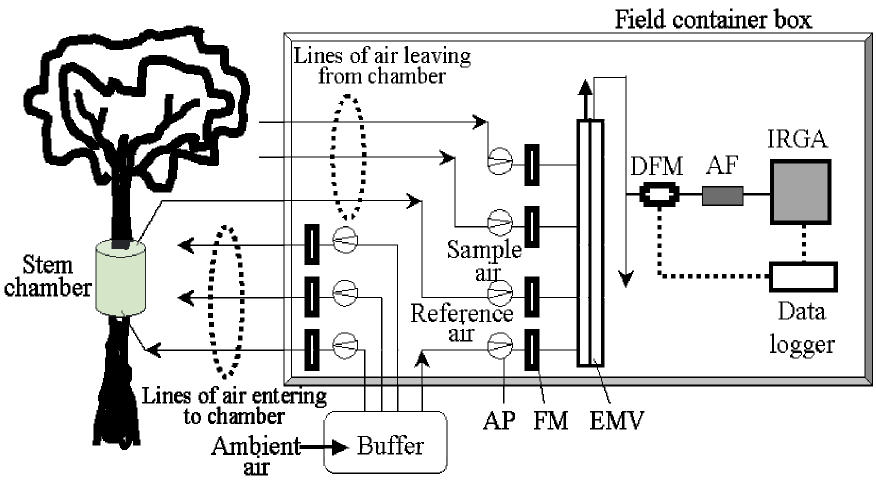

Figure 5. Continuous measuring open flow system (CMOF) used for measurement of stem respiration rate. AP, air pump; FM, flow meter; EMV, electromagnetic value; DFM, digital flow meter; AF, air filter; IRGA, infra red gas analyzer. Arrows indicate airflow (Kim and Nakane in prep.).

They determined the relationships between stem respiration rates and climatic factors, e.g., temperature, relative humidity, precipitation, photosynthetic photon flux density (PPFD) and ambient CO_2 concentration, and compared stem respiration rates among three species, Japanese red pine, black locust (*Robinia pseudo-Acacia)*

and longstalk holly (*Ilex pendunculosa*). Black locust grows on edges and gaps of the forest, while longstalk holly is the dominant species of the shrub layer.

Kim and Nakane (*in prep.*) reported that diurnal courses of air temperature inside and outside chambers during the study period were approximately same during clear weather. However, relative humidity decreased more slowly inside than outside the chamber after rainfall, so that average relative humidity was somewhat higher inside than outside chambers. In contrast to the findings of Nakayama (1990) and Yim (2003) for the use of open chambers for soil respiration, where the gas flow rate through the chamber affected the exchange of CO_2 between the soil and the surrounding atmosphere, Kim and Nakane (*in prep.*) did not observe such an effect. The reason may be that a thick bark and closed structure of stem tissue prevented high or slow flow rates from affecting CO_2 effluxes from stem surfaces. Chambers of circular and rectangular types have been commonly used on stem respiration. Kim and Nakane (*in prep.*) also explored chamber design and found that chamber shape and size did not affect stem respiration rates. Results indicate that respiration rates of small stems measured with circular chambers and large stems measured with rectangular chambers were similar.

Patterns of diurnal fluctuation in stem respiration rate were strongly related to PPFD, air and stem temperatures, especially stem temperature, but not to other climatic factors. Rapid changes in air temperature over short time intervals did not affect stem temperature or respiration rates, so that it was better for analysis of the relationship between them to use stem temperature than air (Damesin *et al.* 2002, Figure 6). Stem respiration increased during rainfall after dry weather, so that if scaling up of stem respiration is based on measurements only from short periods, results may be over or underestimated.

In many studies of the response of stem respiration to temperature, time lags have been reported (Lavigne *et al*. 1996, Ryan *et al*. 1995, Edwards and Hanson 1996, Linder and Troeng 1981, Stockfors and Linder 1998, Damesin *et al.* 2002). Although changes in daily mean air and daily mean stem temperature were parallel, Kim and Nakane (*in prep*.) found that a peak of stem temperature occurred 0.7 h after the peak of air temperature within diurnal fluctuation. The lag time may be caused by a difference in responses to sunlight. In the relationship, when stem temperature was used, time lag was short. Ryan *et al*. (1995) reported that the time lag varied among species, e.g., was 0 h for red pine, 5 h for ponderosa pine, 1 h for western hemlock, and 2 h for slash pine. They suggested that species with thicker bark had longer lag periods than species with thin bark. Similar results were observed in this Japanese red pine stand (7 h for the red pine with thick bark, and 2 h for longstalk holly and black locust). It is difficult to clearly explain the lag response by only stem temperature, because stem temperature varies with stem depth and direction (Derby and Gates 1966, Stockfors 2000). Other factors that could impact a lag response are low permeability of gases through the cambium and bark (Stockfors and Linder 1998), or that some CO_2 respired from stem tissue enters the transpiration stream and is carried upward in the xylem sap rather than diffusing outward through the bark (Negisi 1972, 1979). The problem of lag time can be solved by employing the relationship between the daily mean air (or stem) temperature and the daily mean stem respiration, because the daily mean stem

respiration are parallel to the daily mean air and stem temperature (Linder and Troeng 1981). Linder and Troeng (1981) reported that the relationship between the average respiration rate and average temperature over ten-day periods was linear.

Ryan *et al*. (1994) reported that stem respiration of two moist forest trees ranged over 1.24μ mol CO_2 $m^{-2}s^{-1}$ for *Simarouba amara* and 0.83 μ mol CO_2 $m^{-2}s^{-1}$ for *Minquartia guianensis*. Negisi (1982), Ryan (1990), Ryan *et al*. (1995), and Levy and Jarvis (1998) found similar differences among tree species, as did Kim and Nakane (2004) for the red pine, longstalk holly and black locust (0.13, 0.32, and 1.20 μ mol CO_2 $m^{-2}s^{-1}$, respectively at stem temperature 10℃). Q_{10} values were also different among tree species (1.46 for the red pine, 1.73 for longstalk holly, and 2.29 for black locust), although stem respirations were measured for trees of similar diameter (Fig. 7). The Q_{10} value of the red pine was low compared to other literature values, mostly ranging between 2.0 and 2.3 (Sprugel and Benecke 1991), although Ryan *et al.* (1995) measured low values of Q_{10} for *Pinus ponderosa* (1.4) and *Pinus resinosa* (1.3). Long time lags may lead to lower Q_{10} values.

Stem respiration of the longstalk holly was higher (four-fold) than for the dominant red pine (Fig. 7). Therefore, if stem respiration over a year or more is considered, the shrub layer must be considered as an important attributor of total ecosystem stem respiration. For the stand scale of estimation of stem and branch respiration, the difference in these respiration rates between parts of stems and branches, or individuals of the same species, should be examined.

Several micrometeorological techniques, such as the flux-gradient method or eddy covariance, offer the potential to measure net fluxes of water vapor, CO_2 and other trace gases exchanged between ecosystems and the atmosphere with high temporal resolution. Subsequent data analyses allow the calculation of net ecosystem CO_2 exchange, or NEE. Measurements at isolated field sites, along transects, or as part of larger continental networks provided a first step for the spatial integration of processes within an ecosystem, including soils and vegetation (*e.g*., ongoing projects within FLUXNET).

As discussed, however, these net fluxes reflect the balance between different component fluxes, in the case of CO_2, the two opposing fluxes of uptake during photosynthesis and release during respiration. For water vapor, leaf transpiration and soil evaporation are the major contributors to the combined net flux. Studies are complicated by recycling within canopies (*i.e*., refixation of respiratory CO_2 before it leaves the system), or redistribution of water among ecosystem reservoirs. Distinguishing among these components is critical to obtaining insights into the processes underlying ecosystem responses to climate forcing. Furthermore, environmental parameters, such as temperature and soil moisture, differentially affect biological activities. Observing a net annual increase in CO_2 uptake of a forest, for example, is not sufficient to determining whether this is due to an increase in ecosystem photosynthesis or a decrease in ecosystem respiration.

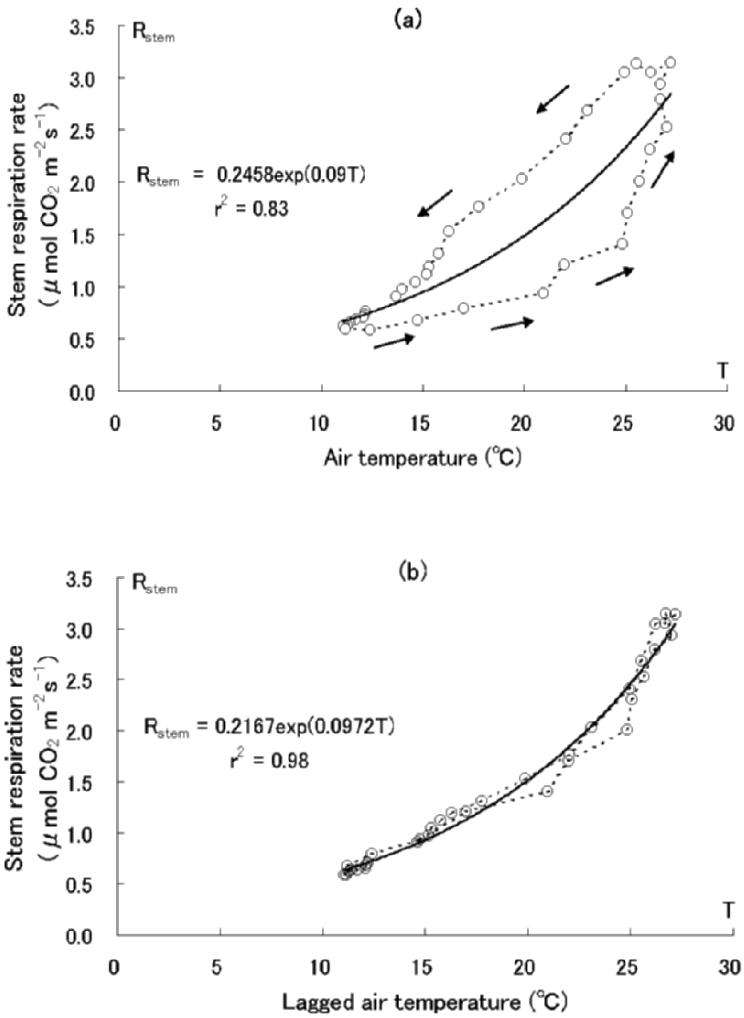

Figure 6. Relationships between temperatures (a: air temperature, b: lagged air temperature) and stem respiration rate of black locust. Lag times were 1.33 h for air temperature and 0.67 for stem temperature. The arrows indicate sequence of measurements (Kim and Nakane in prep.).

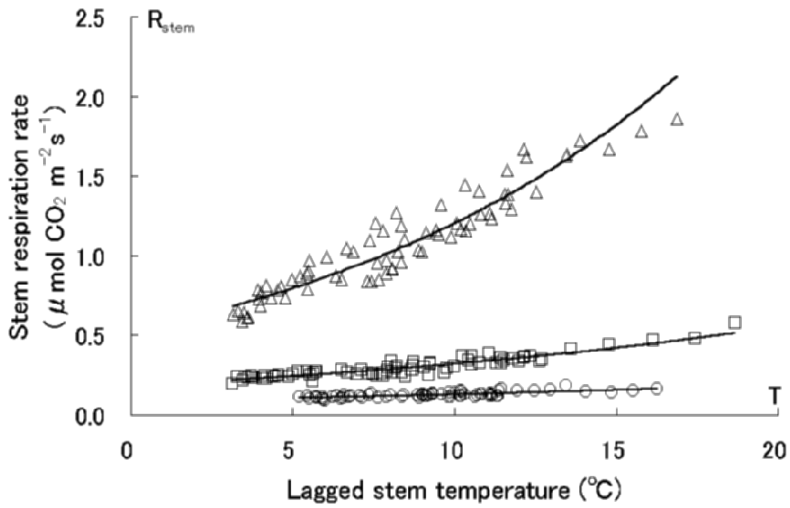

Figure 7. Relationships between stem respiration rates and lagged stem temperatures of Japanese red pine (JRP; ○), longstalk holly (LSH; □), and black locust (BL; △) (Kim and Nakane in prep.). The regression lines were R_{stem}=0.089 exp(0.0381T); r^2=0.56 for JRP, R_{stem}= 0.186 exp(0.0547T); r^2=0.85 for LSH, and R_{stem}=0.527 exp(0.0827T); r^2=0.89 for BL.

2.4 Using stable isotopes for partitioning net ecosystem gas exchange into its component fluxes (Daniel Yakir, Weizmann Inst. of Science, Environmental Sciences and Energy Research, Rehovot, Israel)

Oxygen and carbon stable isotope compositions of different ecosystem components provide a powerful tool towards quantifying the contribution of different components to ecosystem exchange (Yakir and Sternberg 2000). When this tool is used in conjunction with concentration or flux measurements, an even greater amount of information can be derived (*e.g*., Harwood *et al.* 1998, Wang and Yakir 1998). Deciphering the individual fluxes of an ecosystem using stable isotopes can be approximated by knowledge of the isotopic identity of the major ecosystem components, or can be inferred by direct measurements that are currently being developed. These new measurements include combining isotopic and flux measurements, application of relaxed eddy accumulation (REA), or use of hyperbolic relaxed eddy accumulation (Bowling *et al.* 1999a,b). However, to date, there are still difficulties in precisely estimating those individual components.

The partitioning of whole-ecosystem CO_2 fluxes (NEE) can be envisioned as an exercise in solving two equations for two unknowns (gross assimilation of atmospheric carbon and gross release of carbon through respiration), by combining eddy covariance measurements of CO_2, use of relaxed eddy accumulation (for

example) of $^{13}CO_2$ fluxes, and analyses of stable isotope compositions and concentrations (Fig. 8).

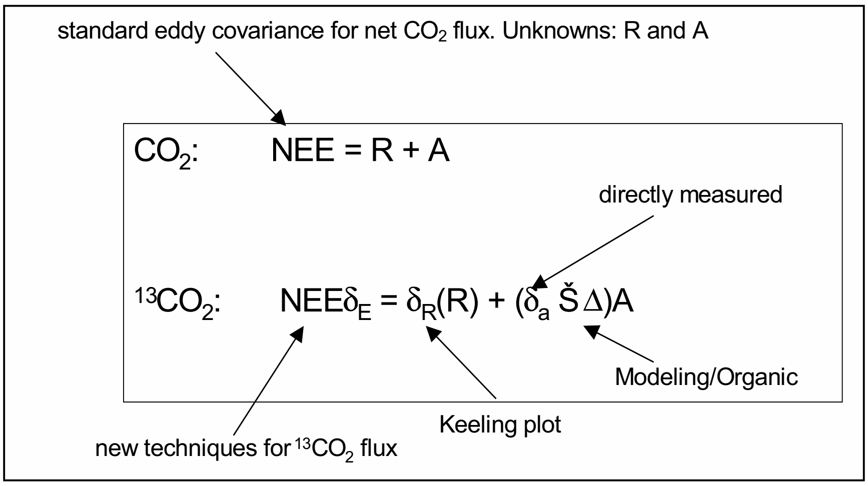

Figure 8. Partitioning of NEE using isotopes, envisioned as an exercise in solving two equations for two unknowns.

In addition to large spatial variations, large temporal variations in isotopic signatures in pools and fluxes typically occur at different time scales: daily, seasonally, and annually. For example, carbon isotope ratios and concentration of canopy CO_2 may well be above (for $\delta^{13}C$) or below (for CO_2) the atmospheric background value if the rate of photosynthesis is high relative to turbulent mixing. This has been observed in tropical forests (Quay *et al.* 1989) and in agricultural crops (Yakir and Wang 1996, Buchmann and Ehleringer 1998). Because photosynthetic discrimination is subject to diurnal and seasonal environmental influences, it is hypothesized that the photosynthetic imprint by the ecosystem will also vary on these time scales and that isotopic discrimination by the ecosystem may fluctuate as well. However, to date, the database on temporal variations is very limited and cannot be used to reject or accept this very plausible hypothesis.

At longer time scales (annual or decadal) further factors come into play. The relative proportion of C3 plants (with average $\delta^{13}C$ values of about -26 ‰) to C4 plants (with average $\delta^{13}C$ values of about -12 ‰) in ecosystems has an important influence on the isotopic identity of respired CO_2. It is expected that European ecosystems, such as grasslands or arable lands, which may have a high proportion of C4 plants, should have respired CO_2 with a less negative $\delta^{13}C$ value than those having a greater proportion of C3 plants such as temperate forests. However, numerous complications can confound these expectations. Different photosynthetic types may dominate some ecosystems, such as croplands and deforested areas at different time periods. Soil organic carbon may retain the isotopic signal of the

previous vegetation for several years due to the long residence times of organic matter in the soil, contributing to differences between the isotopic composition of respired CO_2 and that of the biomass present at the time of sampling. This phenomenon is usually referred as isotopic disequilibrium. Disequilibrium can also arise from soil organic matter being derived from photosynthesis that occurred at a time when the carbon isotopic ratio of atmospheric CO_2 was different than at present (Enting *et al.* 1995, Fung *et al.* 1997). The continuous increase in the concentration of atmospheric CO_2 over more than the past hundred years is due to the addition of ^{13}C-depleted CO_2 from organic sources (fossil fuels and biomass burning), a process that has progressively changed the isotopic composition of the atmosphere (Trolier *et al.* 1996) and all biomass produced from atmospheric CO_2. This, in turn, results in a small difference between the mean ^{13}C values of current biomass production and of soil respiration that is derived from older biomass (Enting *et al.* 1995, Fung *et al.* 1997).

3. CASE STUDIES

3.1 Biological processes influencing fluxes in Pinus forests subject to summer drought (Beverly E. Law, Dept. of Forest Science, Oregon State University, Corvallis, OR 97331 USA)

B. Law and colleagues investigated the impact of summer soil water deficit on processes driving NEE of old-growth and recently regenerating ponderosa pine (*P. ponderosa*) forests in Oregon, USA, using eddy covariance as part of the AmeriFlux program. An old-growth stand had a leaf area index (LAI) of 2.1 and had never been logged. A recently regenerating young stand was predominantly 15-yr-old pine with a LAI of 1.0 (Law *et al.* 2001). Both stands experienced similar meteorological conditions, with moderately cold and wet winters and hot and dry summers. In 2000, the seasonal minimum soil water contents were the same at both sites (0.07 $m^3\ m^{-3}$). Between April and June both stands showed similar rates of tree transpiration peaking at 1.2 mm day^{-1}; thereafter trees at the young stand showed increasing drought stress with canopy stomatal resistance increasing by a factor of five by mid-August relative to values at the old stand (Irvine *et al.* 2002). Over the same period, pre-dawn water potential at the young stand declined from -0.54 to -1.24 MPa, while values at the old stand remained greater than - 0.8 MPa throughout the season. Soil CO_2 efflux at both sites showed large inter-annual variability that could be attributed to soil moisture availability in the deeper soil horizons at the old stand and the quantity of summer rainfall at the young stand (Irvine and Law 2002). Soil respiration at the young stand peaked before seasonal maximal soil temperatures and declined thereafter with declining soil moisture. No substantial seasonal pattern in daytime NEE was observed at either site between April and September (Law *et al.* 2001). This suggests that there were concurrent soil moisture limitations on soil respiration and assimilation at the young stand. Limitations of soil water deficit were not as severe at the old stand, and independent oxygen isotope studies at the site

provide evidence that the mature trees are accessing deep soil water (D. Bowling, pers. comm.). Seasonal patterns of soil efflux at both sites showed influences of soil water limitations that were also reflected in patterns of canopy stomatal conductance, suggesting strong linkages between above- and belowground processes (Irvine and Law 2002).

In young and old ponderosa pine growing in a semi-arid region, drought limitations to soil surface CO_2 fluxes and canopy conductance, and total daytime NEE measured by eddy covariance suggested strong linkages between above- and belowground processes. The young ponderosa pine trees were shallow rooted and the seasonal amplitudes in carbon uptake, transpiration, and respiration were greater than for the old pine site. When there is plenty of water available, the young pine trees take up more carbon per unit leaf area, but when drought occurs, they are more stressed and carbon uptake per unit leaf area is reduced by a larger amount than for the old pine trees. This suggests that any hydraulic advantage that the young trees might have in spring is lost during summer drought, resulting in less net carbon uptake over the year at the young pine site. Biometric data indicate that the old pine site is a sink for CO_2 and the young pine site is still a source of CO_2, likely because productivity of the regrowth is low compared with heterotrophic respiration, particularly from soil (the 15-year old pine site had not reached maximum potential LAI for the region) (Law *et al.* 2001).

3.2 Factors controlling long- and short-term sequestration of atmospheric CO_2 in a mid-latitude forest (Lucy Hutyra, Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138 USA)

The terrestrial biosphere has sequestered significant amounts of atmospheric CO_2, with a major contribution from northern mid-latitude forests (Tans *et al.* 1990, Keeling *et al.* 1996, Barford *et al.* 2001). NEE has been measured for 11 years in a northern mid-latitude forest (Harvard Forest, 42.5N, 72.2W) using eddy covariance (Wofsy *et al.* 1993, Goulden *et al.* 1996, Barford *et al.* 2001). Biometric measurements have been made within the fetch of the tower to elucidate the major pools for carbon and mechanisms of exchange. We determined the carbon budget and responses to environmental forcing including diel, seasonal and inter-annual variations.

Carbon sequestration on the decadal time scale was driven by historical land-use and disturbance, which condition critical characteristics of the ecosystem. This site was abandoned for agricultural use in the 19th century, and by the 1930's a stand of "old field" white pine (*Pinus strobus*) was established. A hurricane in 1938 and subsequent salvage removed 70% of the crown area (Foster *et al.* 1997) and disturbed the soil, allowing establishment of a hardwood stand dominated by northern red oak (*Quercus rubra* L.). Red oak constitutes approximately half the aboveground woody biomass and half the aboveground woody increment (AGWI) at Harvard Forest. Both oak and red maple (*Acer rubrum*) growth has shown significant inter-annual variability, however the absolute oak increment has been increasing throughout the study (Table 1). Oaks have reached approximately half of

their expected life span and likely will continue to store carbon as both biomass and necromass for many decades. As the oaks reach maturity, reproductive investments (particularly masting events) can be expected to compose a greater fraction of carbon allocation.

Biometric data corroborate the mean NEP, when averaged over the 9 years from 1991-2000 (Barford *et al.* 2001). The AGWI dominated carbon uptake, accounting for 70% of 9-yr mean NEP, a typical proportion for northern hardwoods (Whittaker *et al.* 1974). Both growth and respiration depend on carbon fixed in previous years (Kozlowski 1992). Therefore, biometric carbon budgets need not reconcile with NEP in a single year, and several years are required to determine mean rates of C sequestration. We observed three further examples of transient annual imbalances: 1) AGWI composed 100 % of net uptake in 1998 (Fig. 9).

Reconciliation of the 1998 biometric budget with NEP, given the expected below-ground growth, mortality, etc., would be impossible without allowing for the allocation of carbohydrate reserves to AGWI. 2) Radial tree growth in deciduous trees began by production of springwood in early May, up to two weeks before the daily average NEE became negative, and before new leaves started to export carbohydrate. This springwood necessarily derives from stored carbohydrate, thus prior growing conditions affected biometric gains in each growing season. 3) Tree mortality was episodic: 0.4, 1.0, 0.3, 0.4, 1.3 Mg C ha^{-1} yr^{-1} (aboveground) in 1998-2002, respectively. Late season growth appears to differentiate the total strength of the carbon sink (Fig. 9).

Severe summer drought followed by late season rain in 1999 likely dampened the total rate of carbon uptake. A sunny and warm 2002 growing season may have helped propel the growth rate into the fall. Continued observations are needed to reduce uncertainties in the trend of coarse woody debris (CWD) stocks.

Table 1. Aboveground woody biomass accumulation for the dominant tree species at Harvard Forest (percentages are of the annual totals). Units are Mg C ha^{-1} yr^{-1}.

Year	*Total*	*Red oak*	*Red maple*
1998	1.03	0.70 (68%)	0.12 (12%)
1999	1.37	0.78 (57%)	0.19 (14%)
2000	1.61	0.87 (54%)	0.25 (16%)
2001	1.51	0.89 (59%)	0.20 (13%)
2002	1.62	0.92 (57%)	0.23 (14%)

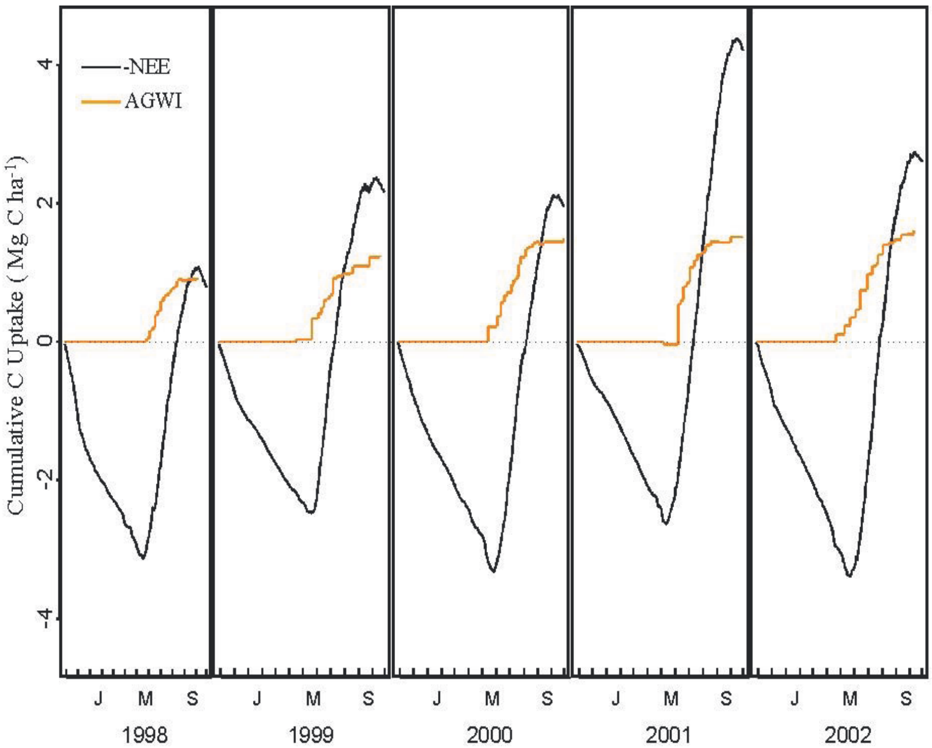

Figure 9. Comparison of seasonal patterns of tower-flux NEE and aboveground woody biomass increment (AGWI) for Harvard Forest over five years.

3.3 Carbon fluxes in old-growth Amazonian rainforest: seasonality and disturbance-induced net carbon loss (Scott Saleska, Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138 USA)

Saleska *et al.* (2003) and Miller *et al.* (2003) obtained eddy flux data from two old-growth sites in the Tapajós National Forest near km 67 (54°58'W, 2°51'S) and km 83 (54°56'W, 3°3'S), respectively, both sites just south of Santarém, Pará, Brazil, from July 1, 2000 to October 1, 2003. NEE measurements, including hourly data for both eddy flux above the canopy and CO_2 storage within the canopy, were obtained for 83% of 19,960 hours. Underestimation of nighttime NEE was evident during calm conditions at both sites, which were corrected for using a procedure developed for mid-latitude forests and adapted, with rigorous testing, for the Tapajós (Miller *et al.* 2003, Saleska *et al.* 2003).

Changes in forest structure and in carbon stored in live wood (due to tree recruitment, growth, and mortality) and dead wood (due to tree mortality inputs and

respiration losses), were also tracked by simultaneous biometric observations at km 67 (Rice *et al.* 2003). We surveyed a total of 19.75 ha along four 1-km transects in the upwind footprint of the km67 eddy covariance tower. These plots contained 170 trees ha^{-1} with a diameter at breast height (DBH) ≥10 cm and with mean aboveground live biomass of 143.7 ± 5.4 Mg C ha^{-1}. An additional 48.0 ± 5.2 Mg C ha^{-1} were in the form of coarse woody debris (CWD).

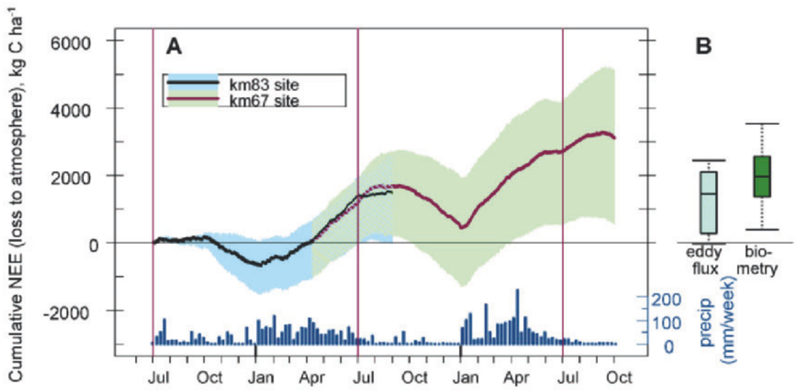

Figure 10. (A) Cumulative NEE at km 83 and km 67 (dark line) –including nighttime correction uncertainty (shaded). The average weekly precipitation (histogram) from July 1, 2000 to October 1, 2002 in the Tapajós National Forest is shown below. Hatched region is overlap period (April 10 – Sept. 1, 2001) prior to selective logging at km 83. The dry season extends from July 1 (vertical lines) to Jan. 1. (B) Annual carbon balance, from eddy flux (Jul 1, 2000 to Jul 1, 2002) and from short-term biometry (July 1999 – July 2001, including estimate of belowground component). Uncertainty in both cases includes potential bias errors (box), and 95% C.I. due to sampling uncertainty (whiskers). We corrected for underestimation of nighttime NEE by filtering out measurements taken during periods of weak mixing, indicated when u* (friction velocity) is below a given threshold (U^*_{thresh}), and replacing them with an estimate based on nearby NEE obtained during well-mixed conditions (when $u^* > U^*_{thresh}$). Analysis (see Saleska et al. 2003) indicates that a best estimate U^*_{thresh} of ~0.22 m sec^{-1} gives nighttime NEE measurements representative of total ecosystem respiration. We estimate a plausible uncertainty associated with this nighttime correction by calculating a low estimate for C-balance using U^*_{thresh} = 0.17, and a high estimate using U^*_{thresh} = 0.30 m sec^{-1}. We believe that the probability that the true balance falls outside this range is small, but it is not rigorously quantifiable.*

Eddy covariance measurements (Fig. 10A) showed ecosystem carbon loss in the wet season and uptake in the dry season, opposite to seasonal cycles of tree growth (Rice et *al.* 2003) and to two different ecosystem model predictions (Botta *et al.* 2002, Tian *et al.* 2001). The seasonal pattern evidently reflects the apparent

dominance of respiration (much enhanced during the wet season) relative to photosynthesis (Goulden *et al.* 2003). Eddy flux derived annual carbon losses were 1.4 (-0.5 to 2.5) and 1.5 (0.3 to 2.6) Mg C ha^{-1} at km 83 and km 67, respectively (Fig 10A). Biometric observations confirmed net loss at the km 67 site (Fig. 10B), showing flux of C (2.0±1.6 Mg C ha^{-1} yr^{-1}) from above and belowground pools of live and dead wood, a consequence of respiration from unusually large stocks of coarse woody debris (Fig. 11).

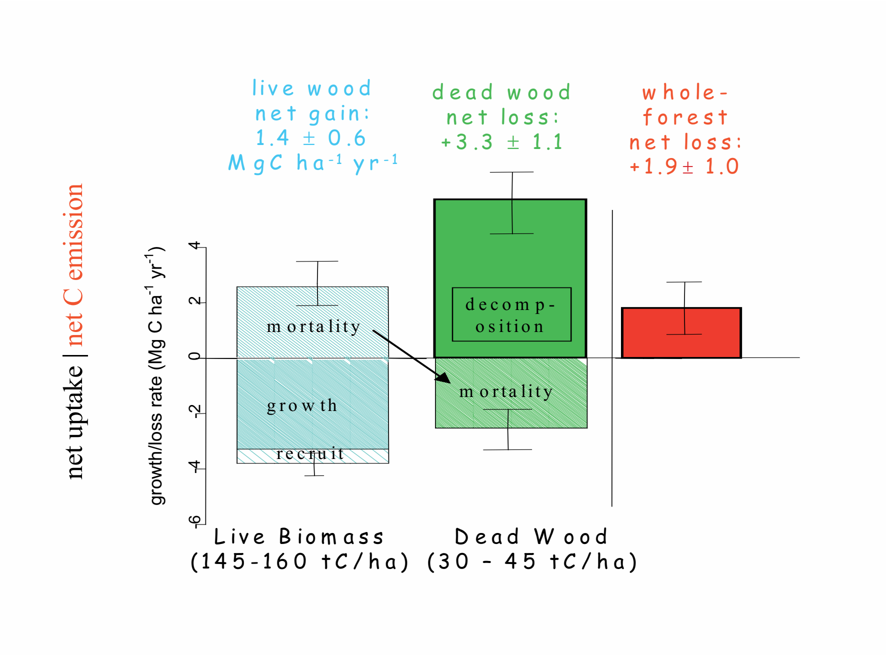

Figure 11. Carbon fluxes from live and dead biomass, 1999-2001 (aboveground only). Recruitment, growth, mortality, and dead wood stock directly measured. Dead wood respiration derived from best estimate decomposition k (0.12±0.02 yr-1) based on field studies near Manaus (Chambers et al. 2001).

The presence of large CWD pools, high recruitment rate, and net accumulation of small-tree biomass, suggest that a period of high mortality preceded the initiation of this study, possibly triggered by the strong El Niño Southern Oscillation events of the 1990s. Transfer of carbon between live and dead biomass pools appear to have led to substantial increases in the pool of CWD, causing the net carbon release we observed.

These results focus attention on the importance of respiration and disturbance for understanding the present and future carbon balance of Amazonian forests. The unexpected seasonality of carbon exchange, dominated by moisture effects on

respiration, may call into question hypothesized carbon cycle responses to ENSO cycles. The observation of disturbance-induced loss implies that carbon balances may depend critically on disturbance dynamics regionally and basin wide. Consequently, if sites are selected with a bias against recent disturbance, extrapolations to the whole basin will consistently overestimate carbon sequestration by Amazonian forests.

3.4. Resolving forest carbon balances at the landscape level, an example from the southeastern United States (Michael Binford, Henry Gholz, Greg Starr, Levant Genc, Grenville Barnes, Timothy Martin and Scot Smith, University of Florida, Gainesville, FL 32611 USA)

Ultimately, if we are to understand and forecast how human activities and natural processes in regions affect large-scale carbon exchange and storage dynamics, we must know and match the scales of human activities, ecosystem processes and observation instruments. International economics doesn't describe whether, why, or how a particular private land owner of a pine forest in Florida decides to harvest a stand in a particular year, thus leading to an "inexplicable" removal of many tons of carbon from the landscape in that year. Neither would AVHRR data, at a spatial grain of 1.1-km, detect the decrease in landscape carbon in this example, because the cut stands are too small and scattered. On the other hand, a wildfire through this forest could offset all the carbon accumulated over the previous decade, however carefully documented from tower flux measurements.

To address this issue it will be necessary to build on carbon exchange and storage measurements from process to ecosystem levels in a range of both managed and unmanaged ecosystem types of the region, inventories of multi-temporal satellite images, comprehensive climate data, spatially-referenced data of land ownership patterns over a long time period, and modeling. One example comes from the southeastern Coastal Plain east of the Mississippi River, which covers nearly 600,000 km^2 of the United States, where such a dataset is being assembled for 1972-2000. This region has a large and rapidly growing human population, as well as a high diversity of natural ecosystems, related mainly to subtle variations in topography, geology and soils within a moderate subtropical climate (Myers and Ewel 1990). Tower flux measurements of NEE are made using eddy covariance and collections of meteorological data. Half-hourly fluxes are then calculated from raw field data, screened and corrected with standard procedures (Moncrieff *et al.* 1997). In some cases, simultaneous measurements have been made below the canopy to help define the partition of fluxes between the canopy and the understory/litter/soil layers, with soil chambers allowing further devolution of the soil/litter component. Collective data can adequately describe NEE dynamics for about half the forested area of Florida. The region has been subject of numerous studies of the structure and carbon dynamics of its component ecosystems (*e.g.,* Gholz and Fisher 1982, Gholz *et al.* 1994, Clark *et al.* 1999, 2003, Ewel and Odum 1984, Leclerc *et al.* 2003, Jokela and Martin 2000). Various empirical and simulation models (*e.g.*, BIOME-BGC, Thornton *et al.* 2002; SPM and SPM2, Cropper and Gholz 1993, Cropper

2000, Clark *et al.* 2001; Linkages, Pastor and Post 1986, Luxmoore *et al.* 2002) are used to integrate and extend the information at several scales.

Widely spaced trees and frequent, low-intensity ground fires characterized the original forests. But most of the "natural" forests in the region today are mixed pine stands, naturally regenerated after abandonment, and often long unburned. Much of the flatter areas of the region were converted to plantations of *Pinus elliottii* since the 1950's. In these stands, management intensity is increasing, with rotations becoming shorter (ca. 20 yrs), herbicide use common early in stand development, fertilization standard, stand densities higher, and use of genetically improved seedlings widespread.

Clark *et al.* (1999, 2003) estimated annual NEE at -1269 and -882 g C m^{-2} yr^{-1} for a recent clearcut, 576 and 603 g C m^{-2} yr^{-1} for a mid-rotation pine plantation, and 741 for a rotation-aged plantation (multiple values are for adjacent years). In contrast, ecosystem respiration (R_{eco}) was similar in magnitude among the sites: 1974 and 2387 g C m^{-2} yr^{-1} at the clearcut, 2346 and 2002 g C m^{-2} yr^{-1} at mid-rotation stand, and 1956 g C m^{-2} yr^{-1} at the rotation-aged stand. Although R_{eco} was similar in magnitude, NEE_{yr} was highly dynamic across the landscape. Their results further argue that daily NEE and GEP, and thus annual NEE, are strongly controlled by LAI and not necessarily the presence of live woody vegetation in forest ecosystems recovering from disturbance. This pattern may also be modulated by climate variability. Subsequent research (Starr, Martin *et al.* in prep.) showed greatly reduced rates of both R_{eco} and GEP as a result of a severe, multi-year drought that ended in 2002. However, both fluxes were affected in proportion, so that annual NEE did not vary significantly throughout the period.

Intense disturbances such as clearcutting lead to a highly dynamic landscape with respect to carbon. The range of annual NEE along the plantation chronosequence (ca. 2000 g C m^{-2} yr^{-1}) is considerably larger than the range of estimates reported across all the sites of the AmeriFlux (-419 to 739 g C m^{-2} yr^{-1}) and CarboEuro (-90 to 736 g C m^{-2} yr^{-1}) networks combined (Table 2). Thus, quantifying the effects of disturbance is clearly key to estimating potential differences in C fluxes resulting from current land use patterns when compared to those that may have occurred across this same landscape in the past, or might in the future.

Estimates from older forests in this landscape indicate that they are long-term sinks for C, although at lower rates than for the even-aged plantations. For example, Powell (2002) (Table 2) found that the annual NEE for a naturally regenerated pine forest adjacent to the plantation sites was similar to that for a forested wetland also nearby (84 and 37 g C m^{-2} yr^{-1} over two years; Clark *et al.* 1999). In addition, the fire regime characterizing this landscape has changed, because the current long return interval/high intensity wildfire regime contrasts strongly with the fast return/low intensity regime that is hypothesized to have occurred in historic forests. Analysis of carbon storage along chronosequences and in growing forests followed over time provide estimates of how much carbon is lost to fires when forests of different ages are harvested or burn.

By using look-up tables and land-cover classifications, and mapping fires, from one time to the next, Binford *et al.* (in prep.) and Genc *et al.* (2001, 2003) estimated

landscape-level NEE and change in storage from 1975-2002 (Figure 12 and 13). Landscape NEE ranged between -10,700 and +35,700 t C yr^{-1} for a 15x15 km study landscape (negative NEE represents a loss from the terrestrial system). The mean was + 26,160 ± 6,899 (s.d.) t C yr^{-1} $landscape^{-1}$. This is equivalent to about 1.15 t C ha^{-1} yr^{-1}, but the variation is so spatially and temporally heterogeneous that the mean value at the hectare scale is virtually meaningless. When all C exchange mechanisms are considered, total landscape C exchange was positive in all but the one year (1998) with the very large fire (total C exchange was -44,600 t yr^{-1}); excluding 1998, the mean C exchange was +24,100 ± 13,560 t C yr^{-1}. This suggests that average annual landscape NEE is positive, but that harvest and wildfires result in large losses in particular years. Inter-annual variability is mainly related to harvesting and fire, with a smaller signal related to variations in annual climate. Much of the carbon removed in this region is used in wood products and paper manufacturing, so that such losses from the bounded landscape do not directly show up as in input to the atmosphere. Interestingly, land ownership *per se* seems not to be a primary factor that directly influences carbon exchange and storage.

Table 2. NEE, ecosystem respiration (Reco) and gross ecosystem production (GEP) for selected managed and natural pine forests, in comparison with the average of a range of European forests (Janssens et al. 2001). Units are g C m^{-2} yr^{-1}. Florida data are from Clark et al. (1999, 2003) and Powell (2002); North Carolina data are from Lai et al. (2002); Oregon data are from Law et al. (2001) and Anthoni et al. (1999).

Site	*Stand age*	*NEE*	*R_{eco}*	*GEP*
		Plantations		
Florida clearcut	1 yr	-1269	1974	705
	2 yr	-882	2386	150
Florida, mid-rotation	10 yr	576	2346	2922
	11 yr	603	2002	2605
Florida, rotation-aged	24 yr	740	1956	2695
	25 yr	610	1907	2517
North Carolina (*P. taeda*)	17 yr	605	1342	1808
		Naturally-regenerated stands		
Florida mixed	ca. 80 yr	178	1581	1759
Oregon Ponderosa Pine	14 yr	0	835	835
	ca. 250 yr	320	892	1212
	ca. 250 yr	270	1010	1280
CarboEuro Sites	various	270	1100	1380

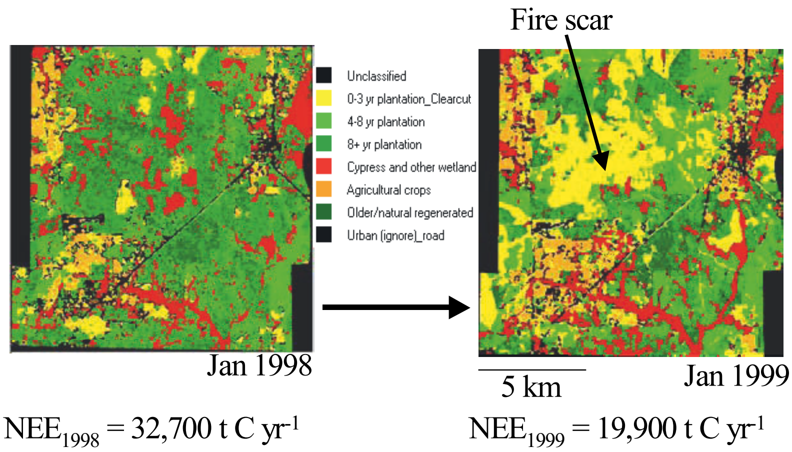

Figure 12. Example landscape carbon dynamics at Alachua Country, FL between 1998 and 1999. A large wildfire in June 1998 removed nearly 60,000 tC from the landscape (Binford et al. in prep.).

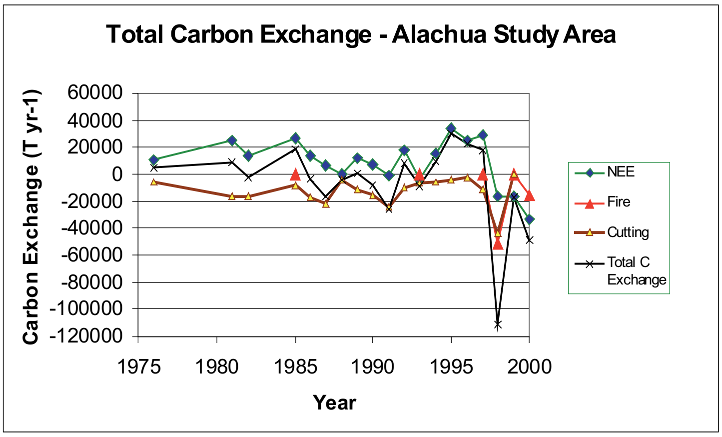

Figure 13. Total carbon exchange (NEE plus harvest plus fire losses) for Alachua County, FL 1975-2000 (Binford et al. in prep.).

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Anthoni, P.M., Law, B.E. and Unsworth, M.H. 1999. Carbon and water vapor exchange of an open-canopied ponderosa pine ecosystem. *Agric. For. Meteorol*. 95: 151-168.

Barford, C.C., Wofsy, S.C., Goulden, M.L., Munger, J.W., Pyle, E.H., Urbanski, S.P., Hutyra, L., Saleska, S.R., Fitzjarrald, D. and Moore, K. 2001. Factors controlling long- and short-term sequestration of atmospheric CO_2 in a mid-latitude forest. *Science* 94: 1688-1691.

Behera, N., Joshi S.K. and Pati D.P. 1990. Root contribution to total soil metabolism in a tropical forest soil from Orissa, India. *For. Ecol. Manage*. 36: 125-134.

Botta, A., N. Ramankutty and Foley, J.A. 2002. *Geophys. Res. Lett*. 29: 1319.

Bowden, R.D., Boone, R.D., Melillo, J.M. and Garrison, J.B. 1993. Contributions of aboveground litter, belowground litter, and root respiration to total soil respiration in a mixed hardwood forest. *Can. J. For. Res.* 23: 1402-1407.

Bowling, D.R., Delany, A.C., Turnipseed, A.A., Baldocchi, D.D. and Monson, R.K. 1999. Modification of therelaxed eddy accumulation technique to maximize measured scalar mixing ratio differences in updrafts and downdrafts. *J. Geophys. Res*. 104: 9121-9133.

Bowling, D.R., Baldocchi, D.D. and Monson, R.K. 1999b. Dynamics of isotopic exchange of carbon dioxide in a Tennessee deciduous forest. *Glob. Biogeochem. Cycl*. 13: 903-922.

Buchmann, N. and Ehleringer, J.R. 1998. A comparison of CO_2 concentration profiles, carbon isotopes, and oxygen isotopes in C4 and C3 crop canopies. *Agric. For. Meteorol*. 89: 45-58.

Chambers, J. Q., J. P. Schimel and A. D. Nobre. 2001. Respiration from coarse wood litter in central Amazon forests. *Biogeochemistry* 52: 115-131.

Clark, K.L., Gholz, H.L., Moncrieff, J.B., Cropley, F. and Loescher, H.W. 1999. Environmental controls over net exchanges of carbon dioxide from contrasting ecosystems in north Florida. *Ecol. Applic*. 9: 936-948.

Clark, K.L., Cropper, W.P., Jr. and Gholz, H.L. 2001. Evaluation of modeled carbon fluxes for a slash pine ecosystem: SPM2 simulations compared to eddy flux measurements. *For. Sci*. 47: 1-8.

Clark, K.L., Gholz, H.L. and Castro, M.E. 2003. Carbon dioxide fluxes from a chronosequence of managed *Pinus elliottii* forests. *Ecol. Applic*. (in press).

Coleman, D.C. 1973. Compartmental analysis of "total soil respiration": an exploratory study. *Oikos* 24: 361- 466.

Cropper, Jr., W.P. 2000. SPM2: A simulation model for slash pine *(Pinus elliottii*) forests. *For. Ecol. Manag*. 126: 201-212.

Cropper, W.P., Jr. and Gholz, H.L. 1993. Simulation of the carbon dynamics of a Florida slash pine plantation. *Ecol. Model.* 66: 231-249.

Damesin, C., Ceschia, E., Goff, N. Le, Otorini, J-M. and Dufrene, E. 2002. Stem and branch respiration of beech: from tree measurements to estimations at the stand level. *New Phytol*. 153: 159-172.

Derby, R.W. and Gates, D.M. 1966. Thetemperature of tree trunks-calculated and observed. *Amer. J. Bot.* 53: 580-587.

Desjardins, R.L., MacPherson, J.I., Mahrt, L., Schuepp, P., Pattey, E., Neumann, H., Baldocchi, D., Wofsy, S., Fitzjarrald, D., McCaughey, H. and Joiner, J.I. 1997. Scaling up flux measurements for the boreal forest using aircraft-tower combinations. *J. Geophys. Res*. 102: 125-29.

Edwards, N.T. 1991. Root and soil respiration responses to ozone in *Pinus taeda* L. seedlings. *New Phytol*. 118: 315-321.

Edwards, N.T. and Hanson, P.J. 1996. Stem respiration in a closed-canopy upland oak forest. *Tree Physiol*. 16: 433-439.

Edwards, N.T. and Harris, W.F. 1977. Carbon cycling in a mixed deciduous forest floor. *Ecology* 58: 431-437.

Enting, I.G., Trudinger, C.M. and Francey, R.J. 1995. A synthesis inversion of the concentration and $\delta^{13}C$ of atmospheric CO_2. *Tellus* 47B: 35-52.

Ewel, K.C. and Odum, H.T. 1984. *Cypress Swamps*. Univ. of Florida, Gainesville, USA.

Ewel, K.C., Cropper, W.P., Jr. and Gholz, H.L. 1987a. Soil CO_2 evolution in Florida slash pine plantations. I. Changes through time. *Can. J. For. Res*. 17: 325-329.

Ewel K.C., Cropper ,W.P. Jr. and Gholz, H.L. 1987b. Soil CO_2 evolution in Florida slash pine plantations. II. Importance of root respiration. *Can. J. For. Res.* 17: 330-333.

Fang, C. and Moncrieff, J. B. 1996. An improved dynamic chamber technique for measuring CO_2 efflux from the surface of soil. *Funct. Ecol*. 10: 297-305.

Fang, C. and Moncrieff, J. B. 1998. An open-top chamber for measuring soil respiration and the influence of pressure difference on CO_2 efflux measurement. *Funct. Ecol*. 12: 319-325.

Foster, D.R., Aber, J.D., Melillo, J.M., Bowden, R.D. and Bazzaz, F.A. 1997. Forest response to disturbance and anthropogenic stress. *Bioscience* 47: 437-445.

Fung, I.Y., Field, C.B., Berry, J.A., Thompson, M.V., Randerson, J.T., Malmstrom, C.M., Vitousek, P.M., Collatz, G.J., Sellers, P.J., Randall, D.A., Denning, A.S., Badeck, F.W. and John, J. 1997. Carbon 13 exchanges between the atmosphere and the biosphere. *Glob. Biogeochem. Cycl*. 11: 507-533.

Genc, L. 2003. Landsat TM-Based Forest Cover Change Case Study (1990-2000) Alachua County Florida. *Abstract of Third Int. Remote Sens. Urban Areas*, Istanbul, Turkey.

Genc, L. 2003. *New method of manipulating Landsat MSS and Landsat TM imaginary for improvements of land cover accuracy*. PhD Dissertation, Univ. of Florida, Gainesville, USA.

Gholz, H.L. and Fisher, R.F. 1982. Organic matter production and distribution in slash pine (*Pinus elliotii*) plantations. *Ecology* 63: 1827-1839.

Gholz, H.L., Linder, S. and McMurtrie, R.E. 1994. Environmental constraints on the structure and productivity of pine forest ecosystems: A comparative analysis. *Ecol. Bull.* 43: 198.

Goulden, M.L., S.D. Miller, M.C. Menton, H.R. da Rocha and H.C. Freitas. 2003. Physiological controls on tropical forest CO_2 exchange. *Ecol. Applic*. (in press).

Goulden, M.L., Munger, J.W., Fan, S.M., Daube, B.C. and Wofsy, S.C. 1996. Measurements of carbon sequestration by long-term eddy covariance: Methods and a critical evaluation of accuracy. *Glob. Change Biol*. 2: 169-182.

Hanson, P.J., Edwards, N.T., Graten, C.T. and Andrews, J.A. 2000. Separating root and soil microbial contributions to soil respiration: a review of methods and observations. *Biogeochemistry* 48: 115-146.

Harwood, K.G., Gillon, J.S., Griffiths, H. and Broadmeadow, M.S.J. 1998. Diurnal variation of $\delta^{13}CO_2$, $\delta C^{18}O^{16}O$ and evaporative site enrichment of $\delta H_2{}^{18}O$ in *Piper aduncum* under field conditions in Trinidad. *Plant Cell Environ*. 21: 269-283.

Haynes, B. E. and Gower S.T. 1995. Belowground carbon allocation in unfertilization and fertilized red pine plantations in northern Wisconsin. *Tree Physiol*. 15: 317-325.

IPCC. 1996. Climate Change 1995. In J.T. Houghton, L.G. Mira, Fiho, B.A. Callender, N. Harris, A. Kattenberg and K. Maskell (Eds.) *The Science of Climate Change*. Cambridge University Press, UK.

Irvine, J. and Law, B.E. 2002. Seasonal soil CO_2 effluxes in young and old ponderosa pine forests. *Glob. Change Biol*. 8: 1183-1194.

Irvine, J., Law, B.E. and Meinzer, F.R. 2002. Water limitations to carbon exchange in old-growth and young ponderosa pine stands. *Tree Physiol.* 22: 189-196.

Janssens, A.I., Lankreijer, H., Matteucci, G., Kowalski, A.S., Buchmann, N. Epron, D., Pilegaard, K., Kutsch, W., Longdoz, B., Grünwald, T., Montagnani, L., Dore, S., Rebmann, C., Moors, E.J., Grelle, A., Rannik, Ü., Morgenstern, K., Oltchev, S., Clement, R., Gumundsson, J., Minerbi, S., Berbigier, P., Ibrom, A., Moncrieff, J., Aubinet, M., Bernhofer, C., Jensen, N.O., Vesala, T., Granier, A., Schulze, E.-D., Lindroth, A., Dolman, A.J., Jarvis, P.G., Ceulemans, R. and Valentini, R. 2001. Productivity overshadows temperature in determining soil and ecosystem respiration across European forests. *Glob. Change Biol*. 7: 269-278.

Jarvis, P.G., Massheder, J.M., Hale, S.E., Moncrieff, J.B., Rayment, M. and Scott, S.L. 1997. Seasonal variation of carbon dioxide, water vapor, and energy exchange of a boreal black spruce forest. *J. Geophys. Res*. 102: 28,953-28,966.

Jensen, L.S., Mueller, T., Tate, K.R., Ross, D.J., Magid, J. and Nielsen, N.E. 1996. Soil surface CO_2 flux as an index of soil respiration in situ: A comparison of two chamber methods. *Soil Biol. Biochem*. 28: 1297-1306.

Jokela, E.J. and Martin, T.A. 2000. Effects of ontogeny and soil nutrient supply on production, allocation, and leaf area efficiency in loblolly and slash pine stands. *Can. J. For. Res*. 30: 1511-1524.

Kanemasu, E.T., Powers, W.L. and Sij, J.W. 1974. Field chamber measurements of CO_2 flux from soil surface. *Soil Sci*. 118: 233-237.

Keeling, R.F., Piper, S.C. and Heimann, M. 1996. Global and hemispheric CO_2 sinks deduced from changes in atmospheric O-2 concentration. *Nature* 381: 218-221.

Kira, T. 1976. Outline of terrestrial ecosystem. *Handbook of Ecology* 2. Kyoritsu Shuppan, Tokyo.

Kirita, H. 1971. Re-examination of the absorption method of measuring soil respiration under field conditions Ⅳ. An improved absorption method using a disc of plastic sponge as absorbent holder. *Jpn. J. Ecol*. 21: 119-127.

Kinerson, R.S. 1975. Relationships between plant surface area and respiration in loblolly pine. *J. Appl. Ecol*. 12: 965-971.

Kozlowski, T.T. 1992. Carbohydrate sources and sinks in woody plants. *Bot. Rev*. 58: 107-222.

Lai, C-T., Katul, G., Butnor, J., Ellsworth, D. and Oren, R. 2002. Modelling night-time ecosystem respiration by a constrained source optimization method. *Glob. Change Biol*. 8: 124-141.

Lavigne, M.B., Franklin, S.E., and Hunt, E.R. JR. 1996. Estimating stem maintenance respiration rates of dissimilar balsam stands. *Tree Physiol*. 16: 687-695.

Law, B.E., Thornton, P., Irvine, J., Van Tuyl S. and Anthoni, P. 2001. Carbon storage and fluxes in ponderosa pine forests at different developmental stages. *Glob. Change Biol*. 7: 755-777.

Le Dantec, V., Epron, D. and Dufrêne, E. 1999. Soil CO_2 efflux in a beech forest: comparison of two closed dynamic systems. *Plant Soil* 214: 125-132.

Leclerc, M.Y., Karipot, A., Prabha, T., Allwine, G., Lamb, B. and Gholz, H.L. 2003. Impact of non-local advection on flux footprints over a tall forest canopy: a tracer flux experiment. *Agric. For. Meteorol*. 3081: 1-12.

Lee, M.S., Nakane, K., Nakatsuobo, T. and Koizumi, H. 2003. Seasonal changes in the contribution of root respiration to total soil respiration in a cool-temperate deciduous forest. *Plant Soil*. (in press).

Levy, P.E. and Jarvis P.G. 1998. Stem CO_2 fluxes in two Sahelian shrub species (*Guiera senegalensis* and *Combretum micranthum*). *Funct. Ecol*. 12: 107-116.

Linder, S. and Troeng, E. 1981. The seasonal variation in stem and coarse root respiration of a 20-year-old Scots pine (*Pinus sylvestris* L.). *Forstl. Bundesvers*. 142: 125-139.

Luxmoore, R.J., Hargrove, W.W., Tharp, M.L., Post, W.M., Berry, M.W., Minser, K.S., Cropper, W.P. Jr., Johnson, D.W., Zeide, B., Amateis, R.L., Burkhart, H.E., Baldwin, V.C. Jr., Peterson, K.D., Fox, S., McNulty S.G. and Mickler R.A. 2002. Addressing multi-use issues in sustainable forest management with signal-transfer modeling. *For. Ecol. Manage*. 165: 295-304.

Maier, C.A., Zarnoch, S.J. and Dougherty, P.M. 1998. Effects of temperature and tissue nitrogen on dormant season stem and branch maintenance respiration in a young loblolly pine (*Pinus taeda*) plantation. *Tree Physiol*. 18: 11-20.

Malhi, Y., Baldocchi, D.D. and Jarvis, P.G. 1999. The carbon balance of tropical, temperate and boreal forests. *Plant Cell Environ*. 22: 715-740.

Miller, S.D., Goulden, M.L., Menton, M.C., da Rocha, H.R. and Freitas, H.C. 2003. Annual CO_2 exchange by a tropical forest. *Ecol. Applic*. (in press).

Mizoguchi, Y., Ohtani, Y., Watanabe, T., Yasuda, Y. and Okano, M. 2003. Long-term continuous measurement of CO_2 efflux from a forest floor using dynamic closed chambers with automatic opening/closing capability. *Jpn. J. Ecol*. 53: 1-12.

Mori, S. and Hagihara, A. 1988. Respiration in stems of Hinoki (*Chamaecyparis Obtusa*) trees. *J. Jap. For. Soc*. 70: 481-487.

Moncrieff, J. B., Massheder, J.M., Verhoeh, A., Elbers, J., Heusinkveld, B., Scott, S., de Bruin, H., Kabat, P. and Jarvis, P.G. 1997. A system to measure surface fluxes of energy, momentum and carbon dioxide. *J. Hydrol.* 188-189: 589-611.

Myers, R.L. and Ewel, J.J. 1990. *Ecosystems of Florida*. Univ. Central Florida Press, Orlando, USA.

Nakane, K., Kohno, T. and Horikoshi, T. 1996. Root respiration before and just after clear-felling in a mature deciduous, broad-leaved forest. *Ecol. Res*. 11: 111–119.

Nakane, K., Yamamoto, M. and Tsubota H. 1983. Estimation of root respiration rate in a mature forest ecosystem. *Jpn. J. Ecol.* 33: 397-408.

Nakayama, F. S. 1990. Soil respiration. *Remote Sens. Rev*. 5: 311-321.

Nay, S.M., Mattson, K.G. and Bormann, B.T. 1994. Biases of chamber methods for measuring soil CO_2 efflux demonstrated with a laboratory apparatus. *Ecology* 75: 2460-2463.

Nay, S.M. and Bormann, B.T. 2000. Soil carbon changes: comparing flux monitoring and mass balance in a box lysimeter experiment. *Soil Sci. Soc. Am. J.* 64: 943-948.

Negisi, K. 1972. Diurnal fluctuation of CO_2 release from the bark of a standing *Magnolia obovata* tree. *J. Jap. For. Soc.* 54: 257-263.

Negisi, K. 1974. Respiration rates in relation to diameter and age in stem or branch section of young *Pinus densiflora* trees. *Bull. Tokyo Univ. Forests* 66: 209-222.

Negisi, K. 1979. Bark Respiration rate in stem segments detached from young *Pinus densiflora* trees in relation to velocity of artificial sap flow. *J. Jap. For. Soc*. 61: 88-93.

Negisi, K. 1982. Diurnal fluctuations of the stem bark respiration in relationship to the wood temperature in standing young *Pinus densiflora*, *Chamaecyparis obtuse* and *Quercus myrsinaefolia* trees. *J. Jap. For. Soc.* 64: 315-319.

Norman, J.M., Garcia, R. and Verma, S.B. 1992. Soil surface CO_2 fluxes and the carbon budget of a grassland. *J. Geophys. Res*. 97: 18845-18853.

Norman, J.M., Kucharik, C.J., Gower, S.T., Baldocchi, D.D., Crill, P.M., Rayment, M., Savage, K. and Striegl, R. G. 1997. A comparison of six methods for measuring soil-surface carbon dioxide fluxes. *J. Geophys. Res.* 102: 28,771-28,777.

Ogawa, K., Hagihara, A. and Hozumi, K. 1985. Growth analysis of a seedling community of *Chamaecyparis obtuse* (I) Respiration consumption. *J. Jap. For. Soc*. 67: 218-227.

Ohashi, M., Gyokusen, K. and Saito, A. 2000. Contribution of root respiration to total soil respiration in a Japanese cedar (*Cryptomeria japonica* D. Don) artificial forest. *Ecol. Res*. 15: 323-333.

Pastor, J. and Post, W.M. 1986. Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. *Biogeochemistry* 2: 3-27.

Powell, T. 2002. *Carbon, water and energy exchange for a mature, naturally regenerated pine forest in north-central Florida*. MS Thesis, Univ. Florida, Gainesville, USA.

Quay, P., King, S. and Wilbur, D. 1989. $^{13}C/^{12}C$ of atmospheric CO_2 in the Amazon Basin: forest and river sources. *J Geophys. Res*. 94: 18327-18336.

Raich, J.W. and Schlesinger, W.H. 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus* 44B: 81-99.

Rayment, M.B. and Jarvis, P.G., 1997. An improved open chamber system for measuring soil CO_2 effluxes in the field . *J. Geophys. Res*. 102(D24): 28779-28784.

Rice, A.H., Pyle, E.H., Saleska, S.R., Hutyra, L., Palace, M., Keller, M., de Camargo, P.B., Portilho, K., Marques D.F. and Wofsy. S.C. 2003. Carbon balance and vegetation dynamics in an old-growth Amazonian forest. *Ecol. Applic*. (in press).

Rochette, H., Flanagan L.B. and Gregorich, E.G. 1999. Separating soil respiration into plant and soil components using analysis of natural abundance of carbon-13. *Soil Sci. Soc. Am. J*. 63: 1207-1213.

Rochette, P. and Flanagan, L.B. 1997. Quantifying rhizosphere respiration in a corn crop under field conditions. *Soil Sci. Soc. Am. J*. 61: 466-474.

Rochette, P., Gregorich, E.G. and Desjardins, R.L. 1992. Comparison of static and dynamic closed chambers for measurement of soil respiration under field conditions. *Can. J. Soil Sci*. 72: 605-609.

Ryan, M.G. 1990. Growth and maintenance respiration in stems of *Pinus contorta* and *Picea engelmannii*. *Can. J. For. Res*. 20: 48-57.

Ryan, M.G.1991. Effects of climate change on plant respiration. *Ecol. Applic*. 1: 157-167.

Ryan, M.G., Hubbard, R.M., Clark, D.A. and Sanford, R.L.Jr. 1994. Woody-tissue respiration for *Simarouba amara* and *Minquartia guianessis*, two tropical wet forest trees with different growth habits. *Oecologia* 100: 213-220.

Ryan, M.G., Gower, S.T., Hubbard, R.M., Waring, R.H., Gholz, H.L., Cropper, W.P., Jr. and Running, S.T. 1995. Woody tissue maintenance respiration of four conifers in contrasting climates. *Oecologia* 101: 133-140.

Saigusa, N., Yamamoto, S., Murayama, S., Kondo, H., and Nishimura, N. 2002. Gross primary production and net ecosystem exchange of cool-temperate deciduous forest estimated by the eddy covariance method. *Agric. Forest Meteorol.* 112: 203-215.

Saleska, S.R., Miller, S.D., Matross, D.M., Goulden, M.L., Wofsy, S.C., da Rocha, H., de Camargo, P.B., Crill, P.M., Daube, B.C., Freitas, C., Hutyra, L., Keller, M., Kirchhoff, V., Menton, M., Munger,

J.W., Pyle, E.H., Rice A.H. and Silva, H. 2003. Carbon fluxes in old-growth Amazonian rainforests: seasonality and disturbance-induced net carbon loss. *Science* (in review).
Singh, J.S. and Gupta, S.R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Bot. Rev.* 43: 449–528.
Sprugel, D.G. and Benecke, U. 1991. Measuring woody-tissue respiration and photosynthesis. In J.P. Lassoie and T.M. Hinkley (Eds.) *Techniques and Approaches in Forest Tree Ecophysiology* (pp. 329-355). CRC Press, Boca Raton, FL, USA.
Stockfors, J. 2000. Temperature variations and distribution of living cells within tree stems: implications for stem respiration modeling and scale-up. *Tree Physiol*. 20: 1057-1062.
Stockfors, J. and Linder, S. 1998. Effect of nitrogen on the seasonal course of growth and maintenance respiration in stems of Norway spruce trees. *Tree Physiol*. 18: 155-166.
Tans, P.P., Fung, I.Y. and Takahashi, T. 1990. Observational constraints on global atmospheric CO_2 budget. *Science* 247: 1431-1438.
Tian, H., Melillo, J.M., Kicklighter, D.W., McGuire, A.D., Helfrich, J., Moore, B. and Vorosmarty, C.J. 2000. Climatic and biotic controls on annual carbon storage in Amazonian ecosystems. *Glob. Ecol. Biogeogr*. 9: 315-335.
Thierron V. and Laudelout H. 1996. Contribution of root respiration to total CO_2 efflux from the soil of a deciduous forest. *Can. J. For. Res*. 26: 1142-1148.
Troiler, M., White, J.W.C., Tans, P.P., Masarie, K.A. and Gemery, P.A. 1996. Monitoring the isotopic composition of atmospheric CO_2: Measurements from the NOAA global air sampling network. *J. Geophys. Res.* 101: 25897-25916.
Valentini, R., Matteucci, G., Dolman, A.J., Schulze, E.-D., Rebmann, C, Moors, E.J., Granier, A., Gross, P., Jensen, N.O., Pilegaard, K. *et al.* 2000. Respiration as the main determinant of carbon balance in European forests. *Nature* 404: 861-865.
Wang, X.F. and Yakir, D. 1998. Non-climatic variations in the oxygen isotopic composition of plants. *Glob. Change Biol.* 4: 835-850.
Whittaker, R.H., Bormann, F.H., Likens, G.E. and Siccama, T.G. 1974. Hubbard Brook Ecosystem Study: forest biomass and production. *Ecol. Monogr*. 44: 233-252.
Wofsy, S.C., Goulden, M.L., Munger, J.W., Fan, S.M., Bakwin, P.S., Duabe, B.C., Bassow, S.L. and Bazzaz, F.A. 1993. Net exchange of CO_2 in a mid-latitude forest. *Science* 260*:* 1314-1317.
Xu, M., Debiase, T.A., Qi, Y., Goldstein, A. and Liu, Z. 2001. Ecosystem respiration in young ponderosa pine plantation in the Sierra Nevada Mountains, California. *Tree Physiol*. 21: 309-318.
Yakir, D. and Sternberg, L. 2000. The use of stable isotopes to study ecosystem gas exchange. *Oecologia* 123: 297-311.
Yakir, D. and Wang, X.F. 1996. Fluxes of CO_2 and water fluxes between terrestrial vegetation and the atmosphere estimated from isotope measurements. *Nature* 380: 515-517.
Yim, M.H. 2003. *Comparison of chamber methods for measuring soil respiration under field and laboratory conditions.* Doctoral Thesis. Hiroshima University, Japan.
Yoda, K., Shinozaki, K., Ogawa, H., Hozumi, K. and Kira, T. 1965. Estimation of the total amount of respiration in woody organs of trees and forest communities. *J. Biol. Osaka City Univ*. 16: 15-26.
Yokota, T. and Hagihara, A. 1995. Maintenance and growth respiration of the aboveground parts of young field-grown hinoki cypress (*Chamaecyparis obtusa*). *Tree Physiol*. 15: 387-392.

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LECH RYSZKOWSKI & ÜLO MANDER

CHAPTER 7

GAS EMISSIONS FROM BUFFER ZONES IN AGRICULTURAL LANDSCAPES - RESULTS EVALUATION OF THE VIII INTECOL CONGRESS SYMPOSIUM

1. THE RATIONALE OF THE SYMPOSIUM

Increasing productions farmers subsidize energy in order to simplify plant cover structure both within cultivated fields (selection of genetically uniform cultivars and weeds elimination) and within agricultural landscapes (elimination of not productive elements of landscapes like woods, hedges, mid-field small wetlands or ponds and so on being obstacles for work of agromachines). Farmers interfere with natural matter cycles directly by input of fertilizers and pesticides or indirectly by decreasing stocks of organic matter in soils which undermine agroecosystems capacities for chemical storing.

These effects of farmers' activities result in the development of a less complex network of interrelations among the components of agroecosystems. As a consequence of this functional simplification, relationships among agroecosystems components are altered, so that there is less tie-up in local cycles of matter. Hence increased leaching, blowing off, volatilisation and escape of various chemical compounds and materials from agroecosystems are appearing.

Intensive application of mineral fertilizers and large inputs of liquid manure have brought threats to environment resulting in deterioration of ground and surface waters. Non-point sources of pollution caused mainly by agricultural activity are recognised as one of the first rank factors decreasing quality of inland water ecosystems (Stanners and Bourdeau 1995, European Environment Agency 1998, COM 1999).

The cleansing effects of vegetation on subsurface and surface fluxes of chemical compounds carried by water was shown in many studies (*e.g.* Peterjohn and Correll 1984, Lowrance *et al*. 1985, Knauer and Mander 1989, Ryszkowski and Bartoszewicz 1989 and many others). Those studies concerned riparian vegetation strips but also it was shown that shelterbelts (mid-field rows of trees) located in upland parts of a catchment area, can influence subsurface water chemistry by removing elements from the groundwater that is in reach of their roots (Ryszkowski *et al*. 1997). Constructed wetlands for wastewater treatment play also important ecotechnological measures for control of water quality in agricultural catchments

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(Kadlec and Knight 1996, Kuusemets and Mander 1999, Mander *et al*. 2001 and many others).

The majority of studies on buffer zones or constructed wetlands rely on input-output analyses and do not attempt to study in detail the internal processes responsible for any observed effects. There is general assumption that the following processes are important in control of the chemical compounds flows by buffer strips and constructed wetlands: plant uptake, ion exchange and, in relation to nitrogen, volatilisation of NH_4 and denitrification provided that there are substantial inputs of nitrates as well as energy-rich organic compounds and that anoxic conditions prevail (Knowles 1981).

Denitrification leading to evolution of gaseous forms like NO, N_2O and N_2 has been found in numerous studies as significant process in nitrogen removal in riparian buffer zones (Groffman *et al*. 1991, 2000, Hanson *et al*. 1994, Gold *et al*. 1998). In the majority of these studies, nitrous oxide (N_2O) fluxes have been measured and only a few studies estimated dinitrogen (N_2) emissions (Groffman and Tiedje 1989, Rudaz *et al*. 1999, Watts and Seitzinger 2000). Emissions of N_2O, which is one of greenhouse gases evoke special concern. Buffer zones of vegetation removing nitrogen in N_2O form from water seeping through their root systems can on side cleanse water but on the other side can enhance build up of nitrous oxide in atmosphere contributing to climate change processes.

The hypothesis of Groffman *et al*. (2000) that riparian buffer strips have the potential to be "hot spots" of N_2O production in the landscape is scrutinized in papers presented at refereed symposium not only in respect to riparian and constructed wetlands but also for situations in shelterbelts and cultivated fields located in upland parts of the catchment basins.

Ammonia volatilisation can be very variable depending on form of nitrogen fertilization (mineral form, manure or liquid manure) application. Ammonia volatilisation rates are often considered as the second important mechanisms to N_2O and N_2 emissions in cultivated fields (Germon and Couton 1989). Its role in nitrogen removal by riparian buffers or shelterbelts is very poorly known.

The other greenhouse gas emissions from riparian and constructed wetlands discussed in the papers of the symposium is methane (CH_4). The comparison of N_2O, N_2 and CH_4 fluxes in riparian buffer zones and constructed wetlands was one of the goals of the symposium.

The most important greenhouse gas is water vapour which is responsible for more than 60 per cent of global warming effect of atmosphere (Jäger and Barry 1990, Mintzer 1992). Evapotranspiration rates of buffer zones are rarely studied. Kędziora *et al*. 1989, Olejnik and Kędziora 1991, Ryszkowski and Kędziora 1993 developed new methods for estimation of heat and water balances under field conditions. Empirically estimated balance fluxes (energy use for evapotranspiration, air and soil heating) were correlated with meteorological characteristics and the parametrization of plant cover structure. Use of the model makes it possible to estimate for buffer zones real evapotranspiration rates under field conditions.

Thus an assessment of emissions from buffer zones of water vapour, N_2O, CH_4 and N_2O has important bearing on development of the environment protection strategy.

The symposium organized by Lech Ryszkowski and Ülo Mander during the VIII INTECOL Congress in Seoul, Korea aimed at discussion of recent progress in studies on emissions of various greenhouse gases including often-neglected water vapour fluxes. Attempts were done to compare emission rates from riparian buffer zones, constructed wetlands as well as upland shelterbelts and cultivated fields. In shelterbelts the processes of chemical compounds processing relevant to nitrogen were analysed in biogeochemical barriers located in upland part of watersheds. These studies were presented in four papers.

2. THE SYMPOSUM ACHIEVEMENTS

2.1 Real evapotranspiration in shelterbelts, riparian stretches of meadows and cultivated fields – Kędziora A., Research Centre for Agricultural and Forest Environment, Poland.

Beside that water vapour is important factor controlling greenhouse warming effects, the water transport of soluble as well as insoluble materials is one of the main routes of the matter exchange between ecosystems. Hence the recognition of mechanisms modifying water fluxes (evapotranspiration and surface and subsurface runoff) is of paramount importance not only for the management of water resources, but also for strategies of environment protection. Evapotranspiration is the biggest component of water balance of all ecosystems in Polish climatic conditions. Usually an evapotranspiration is higher then precipitation in the plant growth season. The long-term studies carried out in Wielkopolska (Poland) region showed that evapotranspiration flux density of ecosystems can be modified by plant cover structure. The impact of plant cover structure on evapotranspiration depends on general weather conditions and moisture of habitat. Bare soil evapotranspiration is controlled by weather conditions and moisture of very thin upper layer of soil. Even after the rain, the moisture of this layer very quickly decreases, reducing intensity of evaporation. As the result, the evaporation of bare soil is very low, reaching during vegetation season (23.03 – 31.10) 320 mm (320 litter of water per square meter) that is only 79% of precipitation (Table 1).

Table 1. Real evapotrabspiration rates in mm (litters per 1m^2) during the plant growth season in various habitats of agricultural landscape in Wielkopolska region (after Ryszkowski and Kędziora 1987)

Habitat	*Evapotranspiration (E)*	*Precipitation (P)*	*(E:P) ·100*
Shelterbelt	578	400	144
Riparian meadow	460	400	115
Rapeseed field	430	400	107
Sugar beet	418	400	104
Wheat	400	400	100
Bare soil	320	400	79

Quite different situation is observed in the case of shelterbelt. Having very high leaf area index and deep root zone, forest can evaporate 578 mm during vegetation season that is 144% of precipitation and 125% of meadow evapotranspiration. Crop ecosystems, as sugar beet field, rapeseed or winter wheat show evapotranspiration equal to about 400 mm that is about 107 – 100% of precipitation. Shelterbelts introduced into crop fields brought about special effects. High saturation water vapor deficit in their crowns, much higher wind speed over crop canopies and deep root zone make shelterbelts work as water pomp intensifying water cycling. But evapotranspiration from the bottom of shelterbelt is very low, reaching about 10% of total evapotranspiration of shelterbelts. During plant growth season evapotranspiration of shelterbelt is about 25% higher then meadow evapotranspiration and 36% higher than crop field evapotranspiration. But, on the other hand, shelterbelts reducing atmospheric water vapor demand reduce the evapotranspiration from protected crop fields, saving about 40 mm water during vegetation season. The evapotranspiration rate essentially increases in the case of heat advection from field to trees conopy. Introduction of shelterbelts reduced alfalfa field evapotranspiration by more than 30%. A bare soil is only one element of agricultural landscape, which conserves water supplies. The other ecosystems use for evapotranspiration during vegetation season more water than incoming as precipitation. The water deficits occur usually in vegetation season in Wielkopolska region can be eliminated during winter period. Shelterbelts introduced into agricultural homogenous landscape gives us two benefits. Increasing of water cycling process by their high rate of evapotranspiration, and they protect water reserves of crop field located between them. Introduction of shelterbelts causes two important effects. The first one is related to changes in water fluxes patterns and second one is increase of water content in atmosphere, which is the most important greenhouse gas (Mintzer 1992, Jäger and Barry 1990). So, management of landscape structure is the best tool for controlling evapotranspiration, and by the same token the structure of water balance in rural area.

The results of reported studies carried out in the agricultural landscape clearly show the controlling effects of shelterbelts and meadows on water fluxes in a landscape. But the emerging picture is quite complicated (Ryszkowski *et al*. 1999). The heat advection processes between cultivated fields and shelterbelts or meadows could augment evapotranspiration rates it these two habitats. This is an unrecognised aspect of the mosaic in plant cover structures influence on water cycling. If the evapotranspiration rate is assumed as index of chemical compounds uptake by plant stand from soil water one can show that shelterbelts have a higher impact than meadows strips and cultivated fields have the lowest impact on uptake of chemicals from the ground water.

2.2 Nitrous oxide, dinitrogen and methane emission in riparian alder forests and constructed wetlands for wastewater treatment - Mander Ü.[1], Teiter S.[1], Lõhmus K.[1] and Augustin J.[2] [1]Institute of Geography, University of Tartu, Estonia, [2]Institute of Primary Production and Microbial Ecology, Centre for Agricultural Landscape and Land Use Research (ZALF), Müncheberg, Germany.

The studies were carried out in riparian alder stands in Southern Estonia (Porijõgi, Mander *et al*. 2001) and close Gumnitz in Brandenburg, Germany as well as in horizontal and vertical flow constructed wetlands in Estonia using the closed chamber method (Hutchinson and Livingston 1993) and the He-O method (Butterbach-Bahl *et al*. 1997).

The measurements of N_2O, N_2 and CH_4 fluxes using closed chamber method and the He-O method were carried out from beginning of 2000 to spring 2003. The He-O method allows one to distinguish between N_2O and N_2 fluxes. According to the results, average rates of N_2O emission measured using the closed chamber method were higher in the study sites in Brandenburg than in southern Estonia, *i.e*. 1.3-2.9 and 0.65-0.7 kg N_2O-N ha^{-1} yr^{-1}, respectively. The average N_2 emission rates in the southern Estonian study sites (measured using the He-O method) exceeded the N_2 emission rates in the Brandenburg sites by up to 17 times, varying from 202-730 in the Estonian sites and from 36-60 kg N_2-N ha^{-1} yr^{-1}, respectively in Brandenburg. This significant difference may be explained by the different microbial communities in the Estonian and German study sites, or by different environmental conditions and therefore different microbial activity. For methane, both German study sites acted as a sink, while Estonian grey alder forest emitted a slight amount of methane; results from the He-O method were quite similar to results from the closed chamber method. The average value of CH_4 emissions was 1.0 to 10.3 and –0.2 to –2,7 kg CH_4-C ha^{-1} yr^{-1} in Estonia and Germany respectively.

In two constructed wetlands the difference between average N_2O and N_2 fluxes was even higher than in riparian forest stands, and in horizontal subsurface flow wetlands was 2.4-32 and 1710-4680 kg N ha^{-1} yr^{-1} for N_2O and N_2, respectively. Vertical flow wetlands showed lower values of N_2 fluxes (850-1600 kg N ha^{-1} yr^{-1}), but relatively high values for N_2O fluxes (40-44 kg N ha^{-1} yr^{-1}). The average CH_4 emission into the atmosphere varied from 3-1060 kg CH_4-C ha^{-1} yr^{-1} in horizontal subsurface flow wetlands, and was somewhat lower in vertical subsurface flow wetlands (110-310 kg CH_4-C ha^{-1} yr^{-1}).

Gaseous emissions from constructed wetlands showed significantly higher values than those from riparian buffer zones. In constructed wetlands we found a remarkable variability in the average emission rates of N_2O-N, N_2-N and CH_4-C, ranging from 1 to 2600, 170 to 130,000 and –1.7 to 87,200 µg m^{-2} h^{-1} respectively. Likewise, the riparian alder forests showed significant differences in emission rate: in the Gumnitz study sites in Brandenburg, Germany, the high N_2O flux and sorption of methane was characteristic, while in the Porijõgi gray alder stands, a significantly higher N_2 flux than that in the Gumnitz study sites was observed throughout the whole study period. This may be explained by somewhat wetter conditions in the Porijõgi riparian area but also by differences in bacterial communities. Some earlier investigations allow one to speculate that the intensive N_2 flux in Porijõgi began recently, about two years ago, as a possible reaction to successive changes in soils and forest stand growth, and significantly lower lateral nitrogen inflow from adjacent fields.

A significantly higher release of all gases studied was observed during the warmer period, although the N_2O flux showed no significant correlation with water temperature. Apparently, the very cold winter of 2002/2003 with air temperature

from –15 to -25 °C for almost two months did influence both water purification efficiency and gas emission. Similar to the purification performance, gaseous emissions in spring and early summer were significantly lower than in autumn.

The most intensive flux of N_2O and CH_4 was observed in chambers installed above the inflow pipes of horizontal flow beds. The vertical flow wetland did emit significantly more N_2O than the horizontal flow beds.

Extremely high peaks of CH_4-C flux were registered in the less aerated parts of wetlands (above the inflow pipes). Correspondingly, the specific potential for global warming (flux rates converted into CO_2 equivalents and divided by population equivalent (pe) value) was relatively high in both vertical flow parts, in the wet bed of the horizontal flow system (6.4 and 5.9 g CO_2 pe^{-1} d^{-1}, respectively), and lowest in the dry bed with lowered water table (1.7 g CO_2 pe^{-1} d^{-1}).

Water table increase in the horizontal flow systems may not significantly influence the efficiency of water purification, although it will increase methane emissions by a few magnitudes. Thus, it is very important to avoid the clogging of pipes, which is normally guaranteed by the regular cleaning of sediments from the septic tank. Clogging of the filter material may have the same influence on the gas emissions as does the clogging of the pipes. Therefore the careful selection of the optimal grain size of the filter material in the construction phase plays a crucial role in the performance of both horizontal and vertical flow wetlands and also in the regulation of trace gas emission from the planted soil/sand filters.

Although the emission of N_2O and CH_4 from constructed wetlands was found to be relatively high, their global influence is not significant. Even if all the global domestic wastewater were treated by wetlands, their share in the trace gas emission budget would be less than 1%.

2.3. The evolution of nitrous oxide and carbon dioxide from mid-field shelterbelts and cultivated fields – Szajdak L. and Ryszkowski L., Research Centre for Agricultural and Forest Environment, Poznań, Poland.

Changes in concentration of various forms of mineral nitrogen (ammonia ions, nitrates and total N) and the evolution of greenhouse gases: CO_2 and N_2O were studied in two shelterbelts (mid-field strips of trees) and adjoining cultivated fields. The measurments of N_2O and CO_2 were conducted with Varian GC3800 equipped with an electron capture at an operating temperature of 340°C and with thermal conductivity detector operating at a temperature of 200°C according to Cabrera *et al*. 1993 description of analysis. The first one shelterbelt of 140 years old and the second one 9-year old were introduced in Hapludalfs soils which constituted also soils of adjoining cultivated fields and are ones with favourable infiltration conditions. The old shelterbelts consists mainly of *Robinia pseudoaccacia* with admixture of *Quercus petraea* and *Q. robur*. Over the 140 years substantial amount of organic carbon accumulated in the soil under shelterbelt and presently the organic C contents is equal to 2.43 per cent. The content of organic carbon in adjoining field is equal to 1.2 per cent. The young shelterbelts is composed of *Quercus petraea* and *Q. robur*, *Larix decidua*, *Pinus sylvestris*, *Sorbus aucuparia*, *S. intermedia*, *Tilia*

cordata and some other tree species. Over 9 years the organic matter did not accumulated and amounted to 0.83 per cent while in the adjoining field it was equal to 0.9 per cent. The difference is not statistically significant. The accumulation of soil organic matter under shelterbelts is the main mechanisms of long-term withdrawal of various elements from recycling in the environment. The studies of total nitrogen, ammonia and nitrate ions have shown higher concentrations of these substances in soils under old shelterbelt than in the cultivated fields. The old shelterbelts had in soil also higher amounts of these substances than in 9-years old one. In the old shelterbelt higher rates of CO_2 evolution were observed than in adjoining field amounting to 156 and 128 per cent of values observed in field when the mean annual values were compared in two consecutive plant growth seasons. In the young shelterbelt evolution of C_2O was similar to the cultivated field. The evolution of N_2O was higher in cultivated fields than, in both shelterbelts although higher rates of nitrous oxide evolution were observed in old than in young shelterbelt (Table 2).

Table 2. The mean N_2O evolution rates ($N\mu{\cdot}m^{-2}{\cdot}h^{-1}{\cdot}$) from soil under the shelterbelts of various ages and adjoining cultivated fields in plant growth season

	Shelterbelts		*Fields adjoining to shelterbelts*	
	7-year old	*140-year old*	*7-year old*	*140-year old*
2000	97	140	240	253
2001	83	112	224	212

The higher rates of N_2O evolution from old shelterbelt than from young one can be explained by higher level of organic matter providing the energy source for denitrification processes. The higher emission rates of N_2O from cultivated fields than both shelterbelts can be explained by higher pH values which promote denitrification as well as higher concentration of nitrates which make substrate for denitrification. These results indicate that nitrogen fertilization in cultivated fields stimulates nitrous oxide emissions while shelterbelts suppress that process.

The recognition of the mechanisms that control emission of nitrous oxide and carbon oxide from soil is important for understanding nitrogen and carbon cycles. Evolution of CO_2 from soil can be used as index of general biological activity of soil biota. The highest mean CO_2 evolution was found from the soil of the 140-year old shelterbelt while soil of the 9-year old shelterbelt and soils of both adjoining fields were characterized by lower and similar (not statistically significant) rates of CO_2 evolution. More than fourfold higher organic nitrogen contents was found in soil of the older shelterbelt when compared with the adjoining field and was associated with only 56 or 28 per cent higher CO_2 emissions. This result indicates that with increasing age of shelterbelt, more and more nitrogen is stored in the resistant to decomposition organic compounds. The accumulation of soil organic matter under shelterbelt is the main mechanism of long-term withdrawal of various elements from the dynamic cycle of transformation in an ecosystem. Estimates of withdrawal rates of nitrogen into humus provided the figure of 1.7 $g{\cdot}m^{-2}yr$ in the

140-year old shelterbelt and 1.4 g·m^{-2}yr for pine afforestation planted in Hapludalf soils (Ryszkowski *et al*. 1997).

From the soils of cultivated fields where nitrates prevail over ammonium ions much higher rates of N_2O evolution were observed than from the soils of shelterbelts where ammonium dominate or make a substantial contribution to the pool of mineral nitrogen. These results confirm estimates of Robertson *et al*. (2000) indicating that N_2O fluxes are much higher from soil under annual crops where fertilizers were applied than from poplar cultivation. It seems that with higher amounts of nitrates in soil, rates of N_2O evolution are also greater, though this relation is not linear and strongly depends on distribution of anaerobic sites in the soil. In newly planted shelterbelt, where shortage of nitrates is apparent (1.0 – 1.2 g·m^{-2} in 150 cm deep soil stratum), the evaluation of N_2O was the lowest in comparison to old shelterbelt and both cultivated fields.

Converting the annual rates of nitrogen storage in humus into hourly intervals for the sake of comparison with N_2O evolution, the estimates of 160 microg N·m^{2}h^{-1} was found for pine afforestation and 190 microg N·m^2 h^{-1} for the 140 years old shelterbelts. These rates are very similar to these for N_2O evolution in the old shelterbelt.

It seems that intensive conversion of nitrate inputs to ammonium ions through assimilation reduction in living organisms and then decomposition of organic nitrogen releasing ammonium as well as the low intensity of nitrification processes are the reasons for lower rates of N_2O release into atmosphere in shelterbelts than in cultivated fields.

2.4. Internal recycling of nitrogen and efficiency of nitrogen flux control in mid-field shelterbelts – Ryszkowski L. and Szajdak L., Research Centre for Agricultural and Forest Environment, Poznan, Poland

Ground water pollution brought about by agriculture is well known phenomenon. Permanent vegetation strips called buffer zones or biogeochemical barriers are introduced into agricultural landscapes to control dispersion of chemical compounds leached out of cultivated fields. The causes of control processes in biogeochemical barriers are still elusive, although the denitrification processes are claimed to be the primary mechanisms of nitrogen removal from inputs of nitrogen compounds with ground water seeping through root systems of the buffer zones. The long term studies on control of nitrogen compounds carried out by the Research Centre for Agricultural and Forest Environment in Poland provided information on various processes effective in diffuse pollution limitation (Ryszkowski 2000, Ryszkowski *et al*. 1997, 1999). The results of these studies together with estimations of urease activity measured by the Hoffman and Teicher (1961) method described by Szajdak and Matuszewska (2000), were used for evaluation of internal N cycling in shelterbelt.

When biomass undergo decomposition ammonia ions are released. This process is controlled at the final stage by the enzyme urease, which is responsible for the conversion of urea nitrogen to ammonia nitrogen (Bremner and Mulvaney 1978).

Estimations of urease activity monitors therefore release of N-NH_3 from decomposing organic compounds which in soil solution appears as N-NH_4^+. The mean values of N-NH_4^+ released from urea in soil segment of 1m x 1m x 0.3m deep were statistically significant higher in shelterbelt of 140 yr. old than in young 9 yr. shelterbelt and both cultivated fields adjoining to shelterbelts (Table 3).

In order to compare all inputs and outputs of nitrogen in the old shelterbelts with N_2O evolution rates and NH_4^+ release from decomposing organic matter all data obtained from other studies (Ryszkowski 2000 data on inputs of N-NO_3, N-NH_4^+, organic nitrogen and their outputs from shelterbelt with ground water, Ryszkowski *et al*. (1997) data on storage of N in humus and wood of trees, plant uptake after Cole and Rapp 1981, and N_2O evolution presented at this symposium by Szajdak and Ryszkowski) were converted into common units expressed in microg·m^{-2}·h^{-1}.

Table 3. Amount of released N-NH_4^+ (g·h^{-1}) from urea in soil segment (1m x 1m x 0.3m) in shelterbelts and cultivated fields

Ecosystem	*Year*		Mean
	2000	*2001*	
Shelterbelt 140 yr (O)	1235.3	775.5	1005.4
Shelterbelt 9 yr (N)	791.0	620.4	705.4
Field adjoining to O	578.1	549.9	565.0
Field adjoining to N	789.6	535.8	662.7

The values for N inputs were as follows (microg·m^{-2}·h^{-1}):

- Precipitation: 165 – 326

Input with ground water through plane in saturated zone of 1m x 2m with slope of water table 0.01 and hydraulic conductivity of 0.5-1.0 m·day^{-1} in respect to:

- N-NO_3^- + N-NH_4^+ varied between 9100-45300
- Organic nitrogen 3300-25800
- Values for N outputs from shelterbelts were as follows:
- N_2O evolution: 83.9 – 192.0
- Discharge with ground water: 730-12 700
- Characteristics of internal recycling of nitrogen were:
- Production of N-NH_4^+ monitored by urease activity $620 \cdot 10^6 – 1235 \cdot 10^6$
- Storage in produced humus - 160-190
- Storage in production of wood - 22
- Plant uptake - 880-1400

Comparing the nitrogen fluxes in shelterbelt one can find that evolution of N_2O from its soil is smaller than nitrogen uptake by plants. N_2 evolution was not estimated in shelterbelt but even if one take very high values provided by Mander *et al*. in paper presented in this symposium the evolution on N_2 is in range of 2337-8449 microg. h^{-1}·m^{-2} and is much lower than internal recycling of nitrogen. The estimates of Mander *et al*. are very high in comparison to Groffman and Tiedje (1989) estimates of mean losses of N to denitrification (N_2O + N_2) being in range of

6.8 μg $N \cdot m^{-2} h^{-1}$ for well-drained forest soils. These last figures are very low in comparison to estimates of N_2O evolution from soil of shelterbelts presented in this symposium by Szajdak and Ryszkowski. The suprising result of presented analysis is very high rate of internal recycling of nitrogen in shelterbelt indicated by estimates of urease activity.

3. EVALUATION OF THE SYMPOSIUM ACHIEVEMENTS

Presented contributions as well as discussion during the symposium showed that quantitative data on gas evolution from shelterbelts and riparian buffer zones as well as constructed wetlands provided new insights concerning the functions of those buffer zones.

There is growing body of ecological knowledge indicating that management of agricultural landscape for its structural diversity is becoming the important pillar of the sustainability of rural areas. Programmes of environmental protection in rural areas should aim not only at introduction environmental friendly technologies of cultivation within farm. They should also be concerned with challenge of how to increase the resistance or resilience of the whole landscape to threats. This could be approached in the case of diffuse water pollution by stimulating natural processes underpinning the control mechanisms by introduction of riparian buffer zones, upland shelterbelts and constructed wetlands.

The reported progress in studies on water cycling in the landscape has shown that because water conductivity in plants is much higher than hydraulic conductivity of the soil in unsaturated zone, trees in shelterbelts or grasses augment evapotranspiration rates which has bearing on two important processes. The first one is connected with heat balance and the second one can help to understand uptake of nutrient by plants with absorbed water. Developed models can be used to estimate of real evapotranspiration rates of landscape with different patterns of plant cover structure. Dynamic picture of water cycling is additionally complicated by heat advection processes, quantitative analysis of which is achievement of Kędziora *et al.* (1989).

The comparisons of emission rates of $N\text{-}N_2O$, N_2 and CH_4 in riparian forest strips and constructed wetlands in Estonia and Germany showed quite substantial variability of results. In the Estonian sites the evolution of dinitrogen was about 17 times higher than in Gumnitz, Germany. Authors of the report propose that observed differences may be explained by differences in composition of microbial communities. Rudaz *et al.* (1999) studying grasslands found that the N_2: N_2O ratio fluctuated strongly during the plant growth season with values ranging from 0.4 to 16.9 assuming the highest values at the time of well – developed vegetation and high content of soil water. Values reported by Mander *et al.* show similar variability. The studies on constructed wetlands have shown that evolution of N_2O and CH_4 is much higher from these constructions than from riparian buffer zones. The studies of Szajdak and Ryszkowski indicated that shelterbelts not only limit passage of nitrogen compounds with ground water seeping through their root systems but also showed that the rate of N_2O evolution is much lower from shelterbelts than from

surrounding cultivated fields. Probably the conversion of N-NO_3^- incoming into shelterbelt with ground water to N-NH_4^+ in assimilatory reduction is the nitrogen – saving mechanism in shelterbelts and meadows which process can be responsible for removal of nitrogen from ground water.

The very high rates of N-NH_4^+ release from urea hydrolysis shown by Ryszkowski and Szajdak can indicate that plants and microbes could play important controlling role in nitrogen cycling of shelterbelts. Sharp decrease of N-NO_3^- concentration in ground water passing under the shelterbelts indicates that biotic demands for this form of nitrogen are high. Nitrogen incorporated into biomass undergoes transformations linked to biological interactions between plants, animals and microbes. Efficiency of infra-system recycling determines dynamic storing capacities of the system and that volume is increased with accumulation of organic matter in growing shelterbelts. The internal nitrogen recycling, which is sensitive to a set of control factors is poorly known. Any imbalance between components of the internal dynamic system of interacting plants, animals and microbes can results in promotion output products such as gaseous nitrogen forms, leaching of mineral or organic nitrogen forms, as well as storing capacities of the systems.

4. REFERENCES

Bremmer, J.M. and Mulvaney, R. 1978. Urease activity in soils. In R.S. Burns (Ed.), *Soil Enzymes* (pp. 149-196). Academic Press, London.

Butterbach-Bahl, K., Willibald, G. and Papen, H. 1997. A new method for simultaneous measurements of N_2 and N_2O- emissions from intact soil cores. *Proceedings of 11-th World Fertilizer Congress of CIEC*. Vol. 2, (pp. 618-624).

Cabrera, M.L., Chiang, S.C., Merka, W., Thompson, S.H. and Pancorbo, O.C. 1993. Nitrogen transformation in surface-applied poultry litter: effect of physical characteristics. *Soil Science Society of America Journal* 57: 1519-1529.

Cole, D.W. and Rapp, M. 1981. Elemental cycling in forest ecosystems. In D.E. Reichle (Ed.), *Dynamic Properties of Forest Ecosystems* (pp. 341-409). Cambridge University Press, Cambridge.

COM. 1999. *Direction towards sustainable agriculture. Commission of the European Communities*. Brussels. 30 pp.

European Environment Agency. 1998. *Europe's Environment: the Second Assessment*. Elsevier Science Oxford UK. 293 pp.

Germon, J.C. and Couton, Y. 1989. Nitrogen balance and gaseous losses in soils. In J.C. Germon (Ed.), *Management Systems to Reduce Impact of Nitrates* (pp. 16-31). Elsevier Applied Science, London.

Gold A.J., Jacinthe P.A., Groffman P.M., Wright W.R. and Puffer R.H. (1998). Patchiness in groundwater nitrate removal in a riparian forest. *Journal of Environmental Quality* 27: 146-155.

Greffman P.M. and Tiedje J.M. 1989. Denitrification in north temperate forest soils: relationships between denitrification and environmental factors at the landscape scale. *Soil Biology and Biochemistry* 21: 621-626.

Groffman, P.M., Axelrod, E.A., Lemunyon, J.L. and Sullivan, W.M. 1991. Denitrification in grass and forest vegetated filter strips. *Journal of Environmental Quality* 20: 671-674.

Groffman, P.M., Gold, A. and Addy, K. 2000. Nitrous oxide production in riparian zones and its importance to national emission inventories. *Chemosphere – Global Change Science* 2: 291-299.

Hanson, G.C., Groffman, P.M. and Gold, A.J. 1994. Denitrification in riparian wetlands receiving high and low groundwater nitrate inputs. *Journal of Environmental Quality* 23: 917-922.

Hoffman, G. and Teicher, K. 1961. Ein Kolorimetrisches Verfahren zur bestimmung der Ureaseaktivitat in Baden. Zeitschrift für Pflanzenernährung. *Düngung und Bodenkunde* 95: 55-63.

Hutchinson G.L. and Livingston G.P. 1993. Use of chamber systems to measure trace gas fluxes. In J.M. Duxbury *et al.* (Eds.), *Agricultural Ecosystems Effects on Trace Gases and Global Climate Change* (pp 1-55). ASA Special Publication No 55, American Soc. of Agronomy, Madison, MI.

Jäger, J. and Barry, R.G. 1990. Climate. In B.L. Tarner *et al*. (Eds.), *The Earth as Transformed by Human Action* (pp. 335-351).

Kadlec, R.H. and Knight, R.L. 1996. *Treatment Wetlands*. Lewis Publishers. New York, 893 pp.

Kędziora, A., Olejnik, J. and Kapuściński, J. 1989. Impact of landscape structure on heat and water balance. *Ecology International* 17: 1-17.

Knauer, N. and Mander, Ü. 1989. Untersuchungen über die Filterwirkung verschiedner Saumbiotope an Gewässern in Schleswig-Holstein. *Zeitschrift für Kulturtechnik und Landentwicklung* 30: 365-376.

Knowles, R. 1981. Denitrification. In F.E. Clark and T. Rosswall (Eds.), *Terrestrial Nitrogen Cycles* (pp. 315-329). Ecological Bulletin (Stockholm) 33.

Kuusemets, V. and Mander, Ü. 1999. Ecotechnological measures to control nutrient losses from catchments. *Water Science and Technology* 40: 195-202.

Lowrance, R., Leonard, R. and Sheridan, J. 1985. Managing riparian ecosystems to control non-point pollution. *Journal of Soil and Water Conservation* 40: 87-91.

Mander, Ü., Kuusemets, V., Öövel, M., Mauring, T., Ihme, R., Sevola, P. and Pieterse, A. 2001. Wastewater purification efficiency in experimental treatment wetlands in Estonia. In J. Vymazal (Ed.), *Nutrient Transformations in Natural and Constructed Wetlands* (pp. 201-224). Backhuys Publishers, Leiden.

Mintzer, J.M. 1992. *Confronting Climate Change, Risk, Implications and Responses*. Cambridge University Press London, 381 pp.

Olejnik, J. and Kędziora, A. 1991. A model for heat and waters balance estimation and its application to land use and climate variation. *Earth Surface Processes and Landforms* 16: 601-617.

Peterjohn, W.T. and Correll, D.L. 1984. Nutrient dynamics in agricultural watershed: observation on the role a riparian forest. *Ecology* 65: 1466-1475.

Robertson, C.P., Paul, E.A. and Harwood, R.R. 2000. Greenhouse gases in intensive agriculture contributions of individual gases to the radiative forcing of the atmosphere. *Science* 289: 1922-1925.

Rudaz, A.O., Walti, E., Kyburz, G., Lehmann, P. and Fuhrer, J. 1999. Temporal variation in N_2O and N_2 fluxes from a permanent posture in Switerland in relation to management, soil water content and soil temperature. *Agriculture, Ecosystems and Environment* 73: 83-91.

Ryszkowki, L. 2000. Protection of water quality against nitrate pollution in rural areas. In S. Wicherek (Ed.), *L'eau; de la cellule au paysage* (pp. 171-183). Elsevier, Paris.

Ryszkowski, L. and Bartoszewicz, A. 1987. Impact of agricultural landscape structure on cycling of inorganic nutrients. In M. Clarholm and L. Bergström (Eds.), *Ecology of Arable Land* (pp. 241-246). Kluwer Academic Publishers, Dordrecht.

Ryszkowski, L., Bartoszewicz, A. and Kędziora, A. 1997. The potential role of mid-field forests as buffer zones. In N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Piney (Eds.). *Buffer Zones: Their Processes and Potential in Water Protection* (pp. 171-191). Quest Environmental, Harpenden UK.

Ryszkowski, L., Bartoszewicz, A. and Kedziora, A. 1999. Management of matter fluxes by biogeochemical barriers at the agricultural landscape level. *Landscape Ecology* 145: 479-492.

Ryszkowski, L. and Kędziora, A. 1987. Impact of agricultural landscape structure on energy flow and matter cycling. *Landscape Ecology* 1: 85-94.

Ryszkowski, L. and Kędziora, A. 1993. Energy control of matter fluxes through land-water ecotones in an agricultural landscape. *Hydrobiologia* 251: 239-248.

Stanners, D. and Bourdeau, P. 1995. *Europe's Environment*. European Environment Agency. Copenhagen, 676 pp.

Szajdak, L. and Matuszewska, T. 2000. Reaction of woods in changes of nitrogen in two kinds of soil. *Polish Journal of Soil Science* 33: 9-17

Watts, S. and Seitzinger, S. P. 2000. Denitrification rates in organic and mineral soils from riparian sites: a comparison of N_2 flux and acetylene inhibition methods. *Soil Biology and Biochemistry* 32: 1383-139.

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CHAPTER 8

LANDSCAPE ECOLOGY: MONITORING LANDSCAPE DYNAMICS USING SPATIAL PATTERN METRICS

1. INTRODUCTION

Habitat evaluation at relatively large geographic scales is becoming increasingly more common as biologists confront issues such as biodiversity, fragmentation, and ecosystem management (Roseberry and Hao 1995). This emphasis on larger scales has been made feasible by the availability of remotely sensed data (O'Neill *et al*. 1999). Satellite imagery can be interpreted for land cover and provides an economical approach to studying large areas (O'Neill *et al*. 1992). The development of geographical information systems (GIS) software provides the tools for handling the large spatial data sets; the technical capabilities of satellite imagery together with GIS technology offers an ideal combination for analysis of landscape condition (O'Neill *et al*. 1999).

Landscape patterns are of major concern in land management and planning, species conservation, and ecological studies. 'Landscape pattern' refers to features associated with the physical distribution or configuration of patches within the landscape (McGarigal and Marks 1995). Some of these features, such as patch isolation or contagion, are measures of the placement of patch types relative to other patch types, the landscape boundary, or other features of interest. Features as patch size and shape are measures of the spatial character of the patches.

The spatial relationship of habitat has been important in assessing the status of a variety of organisms (Davidson 1998). Landscape ecology seeks to understand the ecological function of large areas and hypothesizes that the spatial arrangement of ecosystems, habitats, or communities has ecological implications. Therefore, methods to analyze and interpret heterogeneity at broad spatial scales are becoming increasingly important for ecological studies (Ricotta *et al*. 1997). Changes in the spatial patterns of land use through time are considered to be crucial to the understanding of landscape dynamics and its consequences (Turner and Ruscher 1988). It is important to test a central hypothesis of landscape ecology, i.e. that ecological patterns and processes are linked (Forman and Godron 1986, Turner 1989, Levin 1992).

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Management policies frequently seek to change the structure of a landscape toward particular goals, because it is assumed that the spatial arrangement of elements in a land cover mosaic controls the ecological processes, which operate within it (Haines-Young and Chopping 1996, Gustafson 1998). Characteristic patterns of landscapes presumably are a result of the operation of ecological processes, that is, (ecological) processes generate patterns (*e.g*., spatially scattered habitats originate from fragmentation, see Figure 1), and by analyzing these patterns useful inferences about the underlying processes can be made (Urban *et al.* 1987, Coulson *et al*. 1999). This proposition is known as the 'pattern/process paradigm', and forms a central hypothesis of landscape ecology, a branch of science developed to study ecological processes in their spatial context (Antrop 2001, Stine and Hunsaker 2001). The development of a pattern typology can consequently be useful as a first approach to analyze pattern geometry (Bogaert *et al*. in press). Note that this paradigm can also be interpreted in reverse order: particular patterns will determine or influence the processes active in the landscape (*e.g*., edge effects occurring at the boundary of isolated habitats, see Figure 2).

In order to investigate these relationships between landscape pattern and ecological processes, it is often helpful to describe these patterns in quantifiable terms. This explains the development of a series of (landscape) indices ('metrics') (Hargis *et al.* 1997). As a consequence, conservation strategies and (management) plans now frequently consider not only amounts of habitat that must be retained, but also the spatial configuration of habitats across landscapes of concern (Schumaker 1996, Hong 2001, Botequilha Leitão and Ahern 2002, Hong *et al*. in press). It can therefore be accepted that quantifying the pattern of land cover dynamics is necessary to predict its effects (Groom and Schumaker 1993). One must have measures to describe pattern, so that criteria can be established for relating a particular pattern to its causes and consequences (Levin 1992). Pattern maps are useful because they quantify biologically relevant information that is not necessarily evident from a land cover map (Riiters *et al.* 2000).

This attitude has lead to the development of a plenitude of landscape metrics, to software packages, *e.g*. SPAN ('SPatial ANalysis computer program') (Turner and Ruscher 1988, Turner 1990a, 1990b), SPAN+ (Gustafson and Parker 1991), HISA ('Habitat Island Spatial Analysis') (Gustafson and Parker 1992), FRAGSTATS (McGarigal and Marks 1995), APACK (Mladenoff and DeZonia 1999), or HAMS ('Habitat Analysis and Modeling System') (Roseberry and Hao 1995, 1996), and to software routines to be combined with a GIS (Baker and Cai 1992). It is obvious that this development of software tools will continue. However, despite the increased use of spatial analysis and despite the available measures, experts have not reached an agreement on how to measure landscape patterns (Davidson 1998).

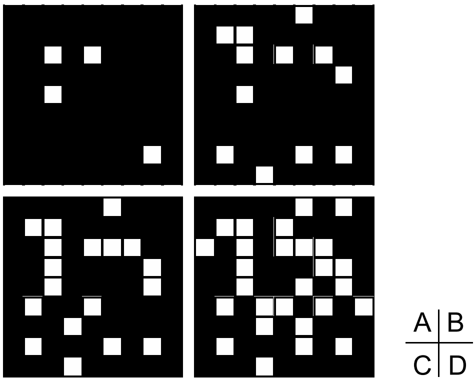

Figure 1. The pattern/process paradigm. As a consequence of spatial landscape transformation processes, typical geometrical pattern features are observed in the landscape. The artificial binary landscapes (9×9 pixels) show habitat (black) and non-habitat (white). Due to habitat loss (randomly allocated; A: 4.9%; B: 14.8%; C: 22.2%; D: 33.3%), habitat connectivity is reduced, and pattern heterogeneity is increased, which leads to a typical fragmentation pattern.

2. INDICES OF LANDSCAPE PATTERN

2.1. Historical context

In the 1980s and 1990s a number of studies explored the utility of landscape metrics in landscape analysis. Some publications are considered milestones in the development of quantitative landscape descriptors. In one of the first studies (O'Neill *et al.* 1988), three metrics were presented: a dominance measure, a contagion measure, and the fractal dimension, describing the geometrical complexity of the landscape. The ratio of intensely managed land to undisturbed area – measuring general land use by humans (Riiters *et al*. 2000) – was also used. The dominance index measures the extent to which one or a few land uses dominate the landscape; the index is based upon information theoretic measures (O'Neill *et al.* 1988). The contagion index – also based on information theory – measures the extent to which land uses are aggregated or clumped. In Riiters *et al*. (1996), alternative contagion calculations are presented, based on attribute adjacency tables (Musik and Grover 1991). Pixels are denoted as 'adjacent' if they have a side in common. Contagion hence refers – for landscape ecologists – to the degree to which mapped attributes are clumped into patches of the same attribute class (Riiters *et al*. 1996). It measures both patch type interspersion (*i.e.*, the intermixing of units of different patch types) and patch dispersion (*i.e.*, the spatial distribution of a patch type) (McGarigal and Marks 1995, Roseberry and Hao 1995). Fractal dimension

was calculated using area-perimeter data (O'Neill *et al*. 1988). If the landscape is composed of simple geometric shapes (squares, rectangles) the fractal dimension will tend towards unity; if many convoluted, irregular shapes appear in the landscape, larger dimensions are observed (Krummel *et al*. 1987). Fractal dimension can be calculated for individual patches (Olsen *et al*. 1993, Bogaert *et al*. 1999b, Bogaert and Rousseau 2001), or for groups of patches, using a regression technique (Krummel *et al*. 1987).

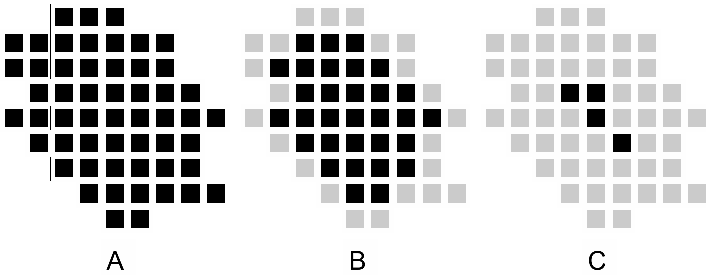

Figure 2. The pattern/process paradigm. Landscape processes are altered or generated by landscape patterns. Presence of edge habitat and interior habitat, due to 'edge effects', are observed for individual patches originating from landscape fragmentation. Panel A shows the original patch, composed of 54 pixels. Panels B and C show two examples of an estimation of the interior and edge habitat. B: formation of interior habitat (black; 31 pixels) and edge habitat (gray; 23 pixels) for a centripetal disturbance with penetration depth of one pixel in both orthogonal directions; a pixel belongs to the interior habitat when surrounded by 4 orthogonal neighbors. C: formation of interior habitat (black; 4 pixels) and edge habitat (gray; 50 pixels) for a centripetal disturbance with penetration depth of two pixels in all orthogonal and diagonal directions; a pixel belongs to the interior habitat if located in the center of a 5×5 square of patch pixels. Based on Bogaert and Impens (1998b) and Bogaert et al. (1999a).

Because no single index can capture the full complexity of the spatial arrangement of patches, a set of indices is frequently evaluated (Dale *et al*. 1994). Multiple indices are also necessary because many metrics do not have a one to one relation between its value and the underlying spatial pattern, even when the measurement is taken for a single patch (He *et al*. 2000). In Turner and Ruscher (1988), a FORTRAN program (SPAN) was presented, to calculate more patch related metrics: patch size and perimeter, proportion occupied by patch category, edges between the categories, and adjacency probabilities. SPAN was later on modified into HISA (Gustafson and Parker 1992), providing measures of isolation (distance to the nearest neighbor, and proximity index, i.e. patch size divided by nearest neighbor

distance (Gustafson and Parker 1994a, 1994b, Gustafson and Gardner 1996)), patch shape (elongation index, calculated as $p \times \sqrt{a}$ with p and a patch perimeter and area respectively, and a linearity index, based on the MAT skeleton in which every patch pixel is represented by its distance to the nearest edge; only the local maximal are kept; elongated patches have skeletons closer to their edges (James 1987, Gustafson and Parker 1992)) and a measure to evaluate edge and interior conditions found in the landscape. As a result of these early studies, a large number of landscape indices may now be found in literature (Haines-Young and Chopping 1996). A comprehensive overview is provided by the FRAGSTATS software package (McGarigal and Marks 1995), calculating metrics at three levels for raster and vector data sets: patch, class, and landscape.

2.2. Index classification

Landscape indices are often divided in categories. In Baskent and Jordan (1995), three categories are distinguished: areal, linear, and topological indices. For practical purposes however, a simpler division would be (McGarigal and Marks 1995, Haines-Young and Chopping 1996): area metrics, edge metrics, shape metrics, core area metrics, nearest neighbor metrics, diversity metrics, and contagion and interspersion metrics. Patch density, mean patch size, and its standard deviation and coefficient of variation could be placed in a separate group (McGarigal and Marks 1995). Note that unlike contagion, which is based upon cell adjacency, interspersion is based on patch adjacency. Intermixture of various conditions affects the quality of habitat available for wildlife (Baskent and Jordan 1995). Landscape pattern can be quantified using statistics in terms of the landscape unit itself (*e.g*., patch size, shape, abundance, and spacing) as well as the spatial relationship of the patches and matrix comprising the landscape (*e.g*. nearest neighbor distance, and amount of contiguous matrix) (Ripple *et al.* 1991). Other subdivisions of metrics separate configuration metrics (quantifying patch geometry and their spatial distribution) from landscape composition metrics (proportion, richness, evenness, dominance) (McGarigal and Marks 1995, Gustafson 1998, Botequilha Leitão and Ahern 2002). Landscape metrics are also to be distinguished from ‘change metrics’, which describe the information regarding changes in a landscape mosaic over time (Botequilha Leitão and Ahern 2002).

Landscape metrics are tools that characterize the geometric and spatial properties of a patch (defined as a spatially homogeneous entity), or of a mosaic of patches (Fortin 1999). It is important to establish the difference of these metrics with spatial statistics (Botequilha Leitão and Ahern 2002). Spatial statistics are tools that estimate the spatial structure of the values of a sampled variable (i.e. point data). In this approach, there are no explicit boundaries (that is, patches are not delineated), and fewer simplifying assumptions are made concerning the spatial configuration of the system (Gustafson 1998). Such analysis seems necessary to choose the appropriate scale for landscape analysis (patch-based or continuous) and to avoid violating assumptions of the analysis methods (Gustafson 1998).

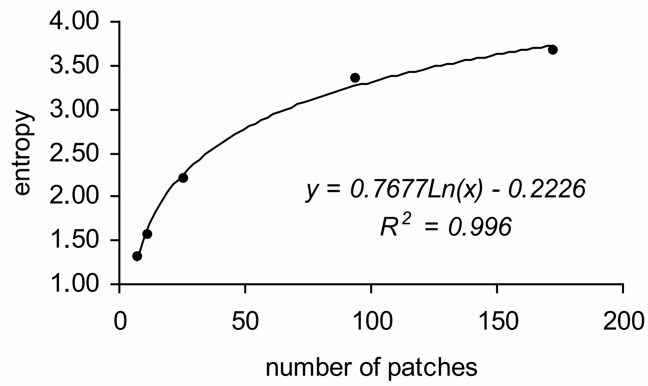

Figure 3. Relationships between pattern metrics. A strong relation is observed between the number of patches (based on 4-connectivity) and landscape entropy for heath land area decline at the Poole Basin (Dorset, UK), as described by Moore (1962) and Webb and Haskins (1980) for the period 1759-1978. The observations refer to 1759 (7 patches), 1811 (11 patches), 1934 (25 patches), 1960 (94 patches), and 1978 (172 patches), respectively. Entropy is calculated after scanning and image enhancement and using the Brillouin metric for a fully censused data set (Margalef 1958, Bogaert and Ceulemans, submitted). The continuous heath land vegetation at this site was fragmented due to intense pressure by growing human populations associated with agricultural expansion, human settlement, mineral extraction, and afforestation.

2.3. Index redundancy

The problem of abundance of indices is profoundly discussed in literature (Gustafson 1998). It has been shown that many indices used to quantify spatial heterogeneity are correlated (O'Neill *et al*. 1988, Riiters *et al.* 1995, Bogaert and Impens 1998b, Hargis *et al.* 1998, Salvador-Van Eysenrode *et al.* 1998, Bogaert *et al*. 1999b, Bogaert *et al.* 2002a) and exhibit statistical interactions with each other (Li and Reynolds 1994). Two examples are described in Figure 3 and 4. Correlation shows that indices are not completely independent, but is sometimes not large enough to drop indices (O'Neill *et al*. 1988). It should be noted that these correlations can be restricted to certain spatial or temporal scales (Figure 5 and 6), or can be limited to particular study areas only.

Many indices appear to measure multiple components of pattern (Li and Reynolds 1994, Riiters *et al*. 1995). Arguments have been put forward to develop indices that

combine multiple components of pattern into a single value (*e.g.*, Bogaert *et al.* 2000b, 2002b), this to reduce the number of variables carried in a multivariate analysis (Scheiner 1992, Riiters *et al.* 1996). Others argue that it is already difficult enough to interpret indices that measure only one component of pattern (Li and Reynolds 1994). A proposed solution is to describe fundamental components of spatial pattern that are independent and to develop a suite of metrics to measure those components (Li and Reynolds 1994, Riiters *et al.* 1996). In Li and Reynolds (1995), spatial heterogeneity is divided in five components, based on theoretical considerations: number of land cover types, proportion of land cover types, spatial arrangement of patches, patch shape, and contrast between neighboring patches. According to Giles and Trani (1999), six important factors exist to describe a mapped area (Table 1).

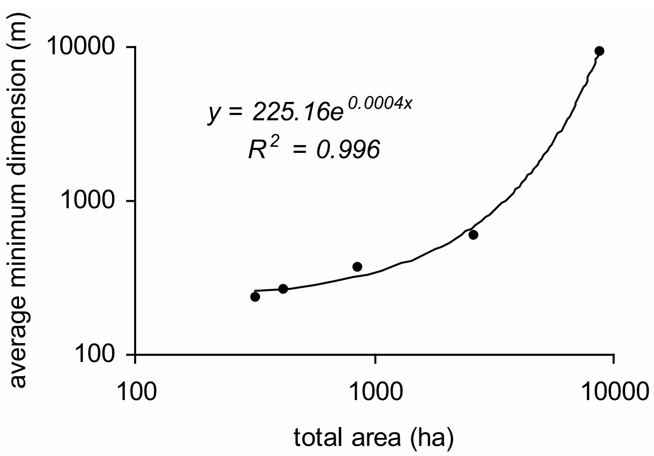

Figure 4. Relationships between pattern metrics. A strong relation is observed between the total area of deciduous woodland and the average minimum dimension of the patches for Cadiz Township (Green County, Wisconsin, USA) for the period 1831-1950. The data correspond to 1831, 1882, 1902, 1935, and 1950 respectively and are based on Curtis (1956) and Burgess and Sharpe (1981). Area decreases continuously in the analyzed time period due to European settlement. The average minimum dimension assumes the wooded area island to be square; deviation from this shape reduces the dimension (Burgess and Sharpe 1981).

The main method to reduce the number of metrics is factor analysis (McGarigal and McComb 1995, Riiters *et al.* 1995, Cain *et al.* 1997, Bogaert and Impens 1998b, Bogaert *et al.* 1999b, Herzog and Lausch 1999, Herzog *et al.* 1999). Using factor analysis, 55 indices were reduced to six independent factors, which could be identified as average patch compaction, overall image texture, average patch shape, patch-perimeter scaling, number of types, and large patch density-area scaling

(Riiters *et al.* 1995). The reduction was based on an analysis of 85 maps of land use and land cover, each representing ~21.6 10^3 km^2 and classified into 37 classes. This study can be considered as an exemplary study of index number reduction and of index redundancy detection. Principal component analysis was applied to evaluate the performance of alternative area-to-perimeter ratios (Bogaert *et al.* 2000a) and to test the behavior of twist number statistics as compared with fractal dimension and compactness measures (Bogaert *et al.* 1999b).

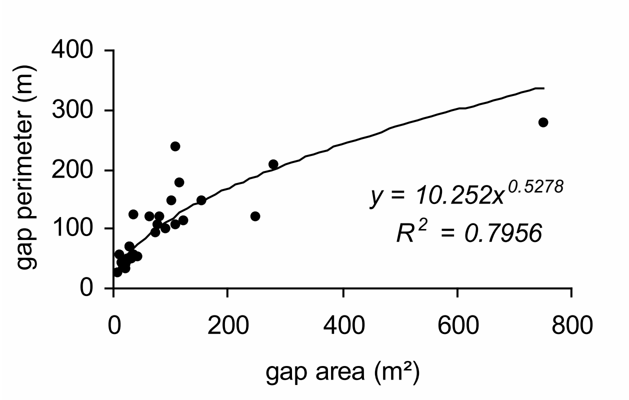

Figure 5. Relationships between landscape features. A strong power relation is observed between the area of 30 canopy gaps and their perimeter. Gap area data are collected in a 13.5 ha plot of 'terra firme' rain forest during a field trip at the Tiputini Biodiversity Station (Ecuador) in March 1998 (Salvador-Van Eysenrode et al., 1998, 1999, 2000; Bogaert et al. 2001). Minimum gap size (sensu Brokaw 1982) to be included in the survey was 4 m^2. Gap perimeter was derived from hemispherical pictures taken with a CID-100 Digital Plant Canopy Imager. Gap shape analysis revealed a tendency to isodiametry, presumably created by the shape and fall orientation of the gap making elements (Salvador-Van Eysenrode et al. 1998).

From a statistical point of view, most indices actually measure one of just a few independent dimensions of pattern, and many are redundant, at least across a range of spatial and attribute scales (Cain *et al.* 1997). Thus, the biological relevance of metrics may be more important than their statistical properties, when it comes to choosing methods to analyze patterns. Another implication is that there appears to be little need to calculate many pattern metrics, unless there is some biological justification for doing so.

One question which a factor analysis cannot answer is the ecological relevance of any particular metric to a land use analyst (Riiters *et al.* 1995). These indices should be chosen that are sensitive to the aspect of landscape pattern of concern (Davidson 1998). Another important question is the relative sensitivity of similar metrics to real land use changes over time.

2.4. Indices for fragmentation

An example of the problems encountered in searching for suitable metrics is the evolution of indices for habitat fragmentation. Fragmentation produces many quantifiable landscape changes: reduced habitat area, increased edges, reduced interior area, patch isolation, and increased number of patches (Davidson 1998). Most of them can be measured separately; however, there is no single measure that captures all aspects (Baskent and Jordan 1995). Often a single measure is therefore mistakenly used as an overall measure (Davidson 1998).

The simplest way to summarize the pattern of fragmentation is through a frequency distribution of patch sizes (Groom and Schumaker 1993). A typical size distribution shows skewness towards smaller values. These data could be completed by using evenness statistics describing the distribution in an alternative way (Table 2). Moreover, these metrics enable to evaluate the relative temporal variability of separate landscape pattern features (Table 3). In both cases, diversity metrics are not used to assess landscape composition, but are used as a pattern metric, hence quantifying configuration.

However, a size distribution does not provide any information concerning other consequences of fragmentation alike the edge effect or isolation (Groom and Schumaker 1993). Moreover, the spatial distribution of patch sizes is sometimes hard to measure and interpret in a complex landscape (Baskent and Jordan 1995). As a solution, two approaches are followed to encounter the lack of an overall measure.

The first is to select the single aspect of fragmentation that is of most concern to the question of interest, *e.g*. patch size (Robinson *et al*. 1992), or aggregation (He *et al.* 2000). However, interpreting single-factor measures is denoted as 'tricky' (Davidson 1998): perimeter length, patch area, interior area, isolation, and other indicators of fragmentation all interact and may change in contradictory directions as fragmentation proceeds.

The second approach to measuring fragmentation is to use several measures to capture the full complexity of the spatial arrangement of patches. This approach is most appropriate when concern is for the integrity of the entire ecosystem, rather than the impact on a single species with specific needs (Davidson 1998). The use of multiple measures requires 'balancing' of the measures, often in different units. A possible solution is combination of multiple metrics as a vector in a hyperspace (Sharpe *et al.* 1981, Bogaert *et al*. 2000b).

Quantifying the pattern of fragmentation is essential to predict its effects. Despite the increased use of spatial analysis and the available measures, experts have not reached an agreement on how to measure patterns of fragmented landscapes, which hampers translation of experimental findings into conservation or management measures (Bogaert 2003). It should be emphasized that the current overview only refers to 'classic' indices, which generate a single value for a patch, a group of patches, or a landscape. Template-based indices, quantifying spatial pattern in locally well-defined subsets of the landscape and consequently not taking into account pixel grouping into patches (see also section 3.1), are not included, although interesting metrics have been presented and applied (LaGro 1991, Riiters *et al.*

2000). A comparison of their analytical value showed however a strong correlation with some classic fragmentation metrics (Bogaert *et al*. 2002c).

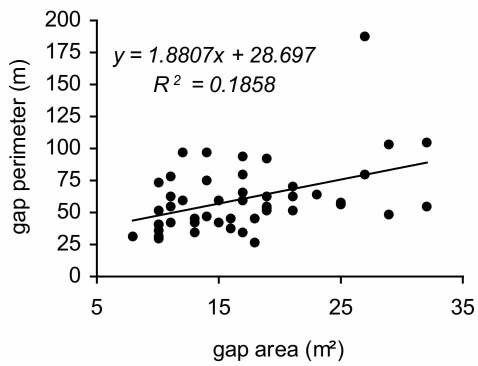

Figure 6. Relationships between landscape features. Only a weak correlation is observed between the area of 48 canopy gaps and their perimeter. Gap area data are collected in a 13.5 ha plot of 'terra firme' rain forest during a field trip at the Tiputini Biodiversity Station (Ecuador) in December 1998 (Salvador-Van Eysenrode et al. 1998, 1999, 2000; Bogaert et al. 2001). Minimum gap size (sensu Brokaw 1982) to be included in the survey was 4 m². Gap perimeter was derived from hemispherical pictures taken with a CID-100 Digital Plant Canopy Imager. Reduction of gap size and shape (relative to Figure 5) are reported to be caused by horizontal closure of gaps with time, presumably caused by in-growth of the surrounding vegetation.

3. TECHNICAL ASPECTS

In this section, two aspects related to raster maps are addressed: patch definition as a function of pixel neighborhood, and patch complexity and its relation to data resolution. Next to raster data structures, another system is widespread for representing spatial data: vector data structure, based on geometric primitives (point, line, area) located by coordinate measurements in a spatial reference system (Chrisman 1997). In general, a vector structure is preferable if the entities being depicted are inherently discrete and must be represented precisely, or if the intended analysis involves measurement or analysis of linear features. A raster structure is preferable e.g. when the entities being depicted have indistinct boundaries or when the data are continuous (Johnston 1998). It can be accepted that for a large extent (*e.g*. satellite imagery) a raster data structure is preferred. The main critique towards raster data is the 'blocky' pattern of spatial features (see also 3.2). However, an

advantage of pixel shape is that the deviation of the true shape – originating from resolution – is stationary, while for vector data, this resolution is often unknown.

3.1. Patch definition and pixel neighborhood

A raster database portrays features as a matrix of equal-area cells that are usually square (Johnston 1998). Other pixel shapes are described (Bribiesca 1997, Ricotta *et al*. 1997) but are used less frequently relative to square-shaped cells. The smallest, non-divisible element is a grid cell or pixel. This is the basic unit of information of a digital image. Spatial primitives, i.e. points, lines, and polygons, can be represented by pixel configurations. Points are reproduced as isolated pixels; lines are reproduced as strings of pixels. Polygons, i.e. patches, are represented by pixel clusters, and are grouped based on pixel neighborhood. Definition of patches is important since a landscape is a mosaic of patches, the components of pattern (Urban *et al.* 1987).

Table 1. Variables hypothesized to be major correlates of measures of landscape pattern described by many observers. After Giles and Trani (1999).

Fundamental variable	**Derivative**
▪ Total area, x_1	
▪ Total classes or relevant units of land use or cover, x_2	
▪ Proportion of the area in the dominant class, x_3	▪ Difference in the proportion of the dominant class and the proportion in the class if the largest three classes had even magnitude, x_4 ▪ Chi-square value relating actual proportions, x_3, to hypothetical evenly distributed proportions, that is x_5
▪ Number of polygons, x_6	▪ Mean polygon size, $x_7=x_1/x_6$ ▪ Variance of polygon size, x_8 ▪ Ratio of mean polygon size to polygon variance, $x_9=x_7/x_8=x_1/(x_6\times x_8)$ ▪ Proportion of filled cells in a contiguity matrix for polygons, x_{10}
▪ Estimated total edge length, x_{11}	
▪ Elevation, x_{12}	▪ Range in elevation, x_{13}

If two pixels have a side in common, i.e. they are 'adjacent', they are denoted as 'nearest neighbors' (Stauffer 1985, Hargis *et al*. 1997). This approach considers four neighboring positions for every pixel not belonging to the border rows or columns of the digital image or map. If two pixels touch only at a corner, they are denoted as 'next-nearest neighbors' (Stauffer 1985, Hargis *et al*. 1997). In this case, eight neighboring positions are considered (see also Figure 2). The two types are also known as 4-connectivity and 8-connectivity, respectively (Bogaert *et al*. 2000a). The type of neighborhood will determine patch definition (*i.e*., the number of patches present in the analysis), and consequently all patch descriptors like size, shape, and isolation (Figure 7).

Table 2. Illustration of the use of metrics (index of largest patch, Gini index and coefficient of variation) to describe the patch size distribution for changes in wooded area in Cadiz Township, Green County, Wisconsin, during the period of European settlement. Data of area and number of patches are based on image analysis of the maps in Curtis (1956). Calculation of the Gini index (G) is described by Weiner and Solbrig (1984) and Rousseau and Van Hecke (1999). G=1 in case of perfect evenness, i.e. all values are equal. Otherwise, G=0. The coefficient of variation (C.V.) is calculated as the ratio of the standard deviation to the mean. Large data variability, i.e. unevenness, results in high values of C.V., which is a measure of relative dispersion. The index of largest patch (L) compares the area of the largest patch with the total area (McGarigal and Marks 1995). In 1831, maximum evenness is found, since only one single patch is present. After 1831 and due to fragmentation, habitat is lost, causing a sharp decrease of patch size evenness in 1882, as shown by G and C.V, and caused by a mixture of large and small patches. Later on, and due to the size homogeneity of the patches, evenness increases. This trend is partially confirmed by L, for which the peak value in 1902 is caused by the presence of a few large patches together with small patches. Further habitat loss in 1950 equalizes patch size. The low value for L in 1882 originates from the fact that several large patches are still present.

	G	*C.V.*	*L*
1831	1.000	0.00	1.000
1882	0.487	1.19	0.097
1902	0.566	1.12	0.112
1950	0.676	0.71	0.068

Table 3. Illustration of the use of evenness metrics (Gini index and coefficient of variation) for changes in wooded area in Cadiz Township, Green County, Wisconsin, during the period of European settlement. Data of area, perimeter, and number of patches are based on Curtis (1956). Data of average minimum dimension are based on Burgess and Sharpe (1981). The average minimum dimension assumes the wooded area island to be square; deviation from this shape reduces the dimension. Calculation of the Gini index (G) is described by Weiner and Solbrig (1984) and Rousseau and Van Hecke (1999). G=1 in case of perfect evenness, i.e. all values are equal. Otherwise, G=0. The Coefficient of variation (C.V.) is calculated as the ratio of the standard deviation to the mean. Large data variability, i.e. unevenness, results in high values of C.V., which is a measure of relative dispersion. G and C.V. indicate that perimeter and number of patches show less temporal dynamics than total area and the average minimum dimension, the latter being the landscape pattern characteristic showing the highest relative variability.

	1831	*1882*	*1902*	*1935*	*1950*	*G*	*C. V.*
Area (ha)	8724	2583	841	419	318	0.411	1.38
Perimeter (km)	–	156.9	97.0	74.8	63.1	0.806	0.43
Number of patches	1	70	61	57	55	0.764	0.56
Average minimum dimension (m)	9340	607	371	272	241	0.316	1.85

For the patch perimeter, the number of neighbors considered also determines the definition of the reference values. Patch perimeter is a major patch characteristic: according to the 'form and function principle' (Forman 1997), patch-matrix interactions will occur at the patch boundary ('edge effect'). The perimeter $p(a)$ of a patch with a pixels is calculated by

$$p(a) = 4a - 2r_a \qquad (1)$$

with r_a the number of shared pixel sides (Bribiesca 1997, Bogaert *et al*. 2000a). Note that $p(a)$ is always an even number, and $r_1 = 0$ and $r_2 \leq 1$. Two types of reference values can be defined: the minimum and the maximum perimeter for a pixels, denoted as $p_{min}(a)$ and $p_{max}(a)$ respectively. Calculation of $p_{min}(a)$ is dependent of a and independent of the type of connectivity considered (Bogaert *et al*. 2000a, Bogaert *et al*. 2002a). If an integer j_1 can be found for which $j_1^2 = a$, then the a pixels can be arranged into a perfect square shape and $p_{min}(a)$ is given by

$$p_{\min}(a) = 4\sqrt{a} = 4j_1 \qquad (2)$$

If no $j_1^2=a$ can be found, then $j_1^2 < a < j_2^2$ with j_1 and j_2 two integers and $j_1 = j_2 - 1$. As long as $a \leq j_1^2 + j_1$, $p_{min}(a)$ is given by

$$p_{\min}(a) = 4j_1 + 2\,. \tag{3}$$

If $a > j_1^2 + j_1$, $p_{min}(a)$ is given by

$$p_{\min}(a) = 4j_1 + 4 = 4(j_1 + 1) = 4j_2 \tag{4}$$

and equals the perimeter of a square of j_2^2 pixels. The type of neighborhood does determine the maximum perimeter for a pixels. In the case of 4-connectivity, the minimum value for r_a equals $(a - 1)$. Every pixel must have at least one side in common with another pixel of the same patch. $p_{max}(a)$ is consequently calculated as

$$p_{\max}(a) = 4a - 2(a-1) = 2(a+1)\,. \tag{5}$$

For 8-connectivity, the minimum value for r_a equals 0. Consequently, $p_{max}(a) = 4a$. The reference values can be used to compare the observed patch perimeter with a theoretical value, indicating extreme patch compactness – for $p_{min}(a)$ – or extreme patch elongation – for $p_{max}(a)$ (Bogaert and Impens 1998b, Bogaert *et al*. 1999b, Bogaert *et al*. 2000a). This analysis can have a predictive value for the presence of interior and edge habitat (Bogaert *et al.* 1999a). It can be accepted that carefully should be decided on neighborhood definition before analysis of landscape pattern data. Especially for elongated, linear structures, the choice between the two neighborhood types will determine the final outcomes considerably. It is a minimum prerequisite that every analysis report includes an indication of the number of neighbors considered.

3.2. Patch complexity and image resolution

Data resolution can be defined as 'the area that is represented by one single pixel' (DeMers 1997), or more generally, 'the degree to which small objects are distinguishable' (Forman and Godron 1986, Forman 1997). Resolution can also be described by the term 'grain' (Milne 1991, McGarigal *et al*. 1995, Forman 1997, Hargis *et al*. 1997), i.e. the minimum spatial (or temporal) resolution of the data. Grain determines the lower limit of what can be studied.

At coarse levels of resolution, polygons appear 'blocky' and lines appear stair-stepped; at finer levels of resolution, a raster representation looks more like a 'real' map, but storage requirements increase exponentially (Johnston 1998). Raster maps show a tendency for upward bias of perimeter length because of the stair stepping pattern of the line segments, and the magnitude of bias will vary in relation to the grain or resolution of the image (McGarigal and Marks 1995, Hargis *et al*. 1997);

the degree of curve roughness is also influenced by pixel resolution. Comparison between images with different resolutions should therefore be handled with caution. While finer resolution raster databases are aesthetically more appealing, the increased detail which they provide may be unnecessary for data analysis (Johnston 1998). The appropriate raster size should be comparable to the scale at which the ecological process of interest is operating (Forman 1997, Hargis *et al*. 1997).

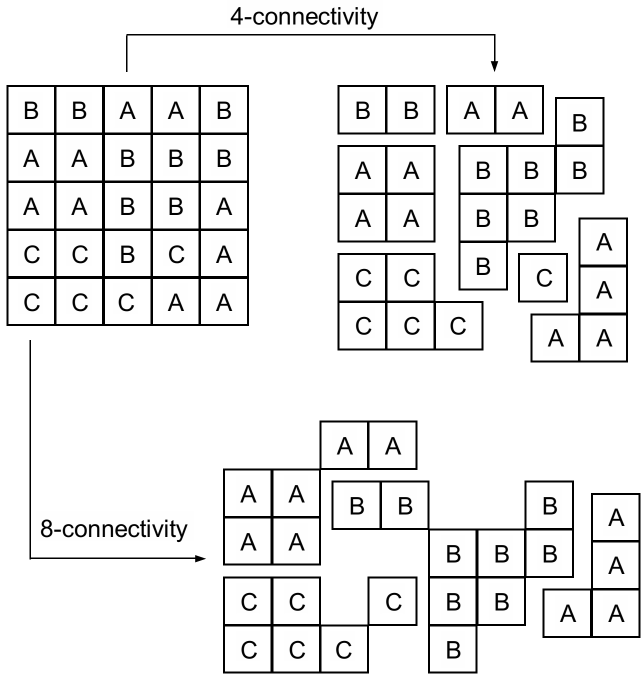

Figure 7. Patch definition in raster images. The type of connectivity considered will determine the final number of patches, patch area distribution, and patch shape complexity. In case of 4-connectivity, more patches are observed relative to 8-connectivity, with less irregular shapes and smaller average area. In the current example, 4-connectivity subdivides the landscape into 7 patches with average size equal to 3.6 pixels. In case of 8-connectivity, only 4 patches are observed, with average patch size equal to 6.3 pixels. A higher degree of patch irregularity is observed due to fusion of patches only touching at a pixel corner, which leads to longer and more convoluted patch perimeters.

Landscape patterns, as observed by digital images generated by remote sensing, do appear or disappear at different resolutions (Farina 1998). Rare land cover types are lost when grain becomes coarser; patchy arrangements disappear more rapidly with increasing resolution than contagious ones (Turner *et al.* 1989, Haines-Young and Chopping 1996). It is the distribution of shape as well as area over all patch types which determines the number of types apparent at any given degree of spatial

aggregation (Turner *et al*. 1989, Turner 1990b). Problems with grain arise when elements of the spatial pattern (*e.g*. patches) are scattered and are as small or smaller than a pixel.

Moreover, the number of different shapes that can be constructed with a fixed area is finite (Guttmann 1982, Bogaert and Impens 1998a), which limits the information content of the raster data layers. This implies also that the possible number of outcomes of landscape metrics will vary with pixel resolution. For a pixels, and considering 4-connectivity, the number of shapes n_a is calculated by (Guttmann 1982, Bogaert and Impens 1998a):

$$n_a \approx 0.317(4.0626)^a a^{-1} e^c \tag{6}$$

with c equal to

$$c = -0.465 a^{-0.87} \tag{7}$$

It should be noted that n_a considers shapes to be different if they do not coincide without rotation or mirror operation. Many of the shapes do however show identical area and perimeter values, but the general trend of increased potential patch complexity with an increased resolution of the data applies. The different shapes for a=4 are shown in Figure 8.

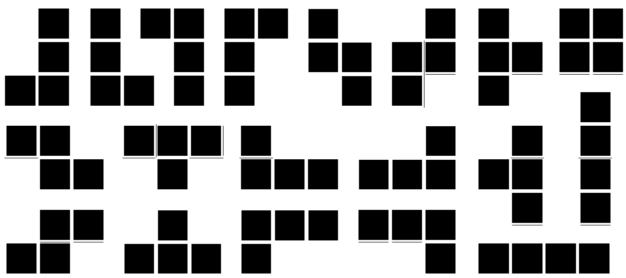

Figure 8. Relation between the potential patch complexity and the number of pixels composing the patch. Illustration of the n_a≈19 different shapes for a=4. Note that some shapes are considered as different, although they show identical shape characteristics, since they are related by a rotation or mirror operation. If rotations and mirror images would be considered identical, the presented group of shapes could be reduced to 5 types. Only the four cardinal directions of a square grid are considered.

The increasing number of possible shapes for up to 20 pixels are listed in Table 4. This increasing potential complexity with increasing resolution is up to today hardly dealt with in landscape structure studies. Often, data aggregation is executed to match different data sets at different resolutions for combination in a GIS. It should

be taken into account that data sets should be available at the scale of the process or pattern of interest, and that resolution coarsening limits the information content and complexity of the data.

Experience with applying indices to landscape analysis has suggested some rules of thumb for scale (O'Neill *et al*. 1996). Grain size should be 2-5 times smaller than the patch or other spatial feature of interest. The landscape extent or size should be 2-5 times larger. In practice, both requirements are easily met in regional assessments using 30-100 m resolution satellite data (O'Neill *et al*. 1999). To compare maps at different scales, it would be convenient if the indices were insensitive to changes in scale; however, examinations suggest that they are very sensitive to scale. Not only map information is influenced by scale, but also often the metrics themselves (Benson and MacKenzie 1995). At extreme values of scale this must of course be true since the pattern itself is distorted at the extremes. Therefore, the practical issue is not addressed by comparing metrics at extreme scales (O'Neill *et al*. 1999). Over a reduced size range, *e.g*. 10-100m, metrics are found to be relatively insensitive for certain indicators and patterns (Wickham and Riiters 1995). Fractal analysis (Krummel *et al*. 1987, Milne 1991) can contribute significantly to this debate, since scale-related phenomena can be described by the fractal dimension.

Table 4. The number of different shapes for patches composed of up to 20 pixels based on the formula of Guttmann (1982). Shapes that are not coinciding without mirror of rotation operation(s) are considered as different. Only the four cardinal directions of a square grid are considered.

a	n_a	a	n_a
1	1	11	135 343
2	2	12	506 152
3	6	13	1 904 962
4	19	14	7 208 744
5	63	15	27 408 466
6	215	16	104 641 842
7	759	17	400 968 600
8	2 725	18	1 541 429 778
9	9 913	19	5 942 885 306
10	36 463	20	22 972 339 971

4. CONCLUDING REMARKS – FUTURE RESEARCH

The future of landscape ecology is a quantitative one: after a purely descriptive stadium, quantitative techniques have gained interest and importance, and have provided improved and more reliable tools for analyzing landscapes, and for relating patterns to processes. The science community owes O'Neill *et al*. (1988), for publishing the first landscape ecology paper of a series presenting analytical tools, especially landscape metrics, to analyze landscape structure.

This evolution of landscape ecology, and more specific the branch of landscape pattern quantification, has however also known many efforts that were less successful. Which metric to use, and when, is still subject to debate, notwithstanding the importance of the outcome of this debate for policy development on land use changes (Bogaert 2003). How to predict the outcomes of land dynamics, if its effects cannot be quantified?

The question whether new metrics are still needed remains unanswered. Up to today, new metrics are still presented (*e.g*., Jaeger 2000, He *et al*. 2000, Bogaert *et al*. 2002b), and validated, and generally it is hard to turn them down on objective reasons: patterns can be so complex, that it seems that an infinite number of metrics will be needed to measure them. Nevertheless, the abundance of metrics will not stimulate their use. Others advocate to return to the 'basics', and try to identify which pattern aspects seem to be independent (Riiters *et al*. 1995, Cain *et al*. 1997, Giles and Trani 1999, O'Neill *et al*. 1999). At present, landscape pattern can be represented as a point in a multidimensional (~5) "state space" of indices (O'Neill *et al.* 1996, Wickham *et al*. 1996), leading to five metrics. The early emphasis on measuring pattern required easily measured parameters and resulted in indices that rely heavily on patch size and perimeter, but there are other possibilities that are now being explored for developing new indices (O'Neill *et al*. 1999): island biogeography theory (MacArthur and Wilson 1967), percolation theory (Stauffer 1985), hierarchy theory (Allen and Starr 1982), and theories originating from economic geography.

Development of new metrics does not exclude novel applications of existing metrics. Pattern changes are indicative for underlying processes, and the pattern of changes can provide insight in the reliability of the observations. In Bogaert *et al.* (2002c), the spatial pattern of NDVI increase in the northern hemisphere was analyzed using fragmentation metrics such as coherence (Jaeger 2000), index of the largest patch (McGarigal and Marks 1985), and contiguity (LaGro 1991). Aggregated or 'coherent' patterns were postulated to be associated with actual changes, while scattered ('not coherent') NDVI dynamics were considered as less reliable (Figure 9).

Future possibilities include the increased use of covariates to improve statistical analysis and understanding of landscape dynamics: experience has demonstrated that non-pattern covariates (*e.g*., erosion, productivity, biodiversity) are needed to relate pattern to ecological endpoints (O'Neill *et al*. 1999). Connectivity, more than its physical equivalent 'connectedness' (Bogaert *et al.* 2000b), seems to be a useful

concept in this approach. Ecological models are needed to relate pattern change to potential impacts on ecosystem function, which will generate new covariates.

Patch-based landscape metrics have been the primary focus of landscape ecological analysis, and are indeed appropriate for a majority of ecological questions. However, the appropriate spatial and temporal scales at which these analyses are applied should be determined by geo-statistical analysis (Fortin 1999), especially when the system property varies gradually in space and/or time (Gustafson 1998).

B	B	B	B	B
A	A	B	B	B
A	A	C	B	A
C	C	C	B	A
C	C	C	A	A

coherent

B	A	C	B	A
C	B	A	C	B
B	A	C	B	A
C	B	A	B	C
B	A	C	A	B

not coherent

Figure 9. Spatial pattern and data quality. Spatial data showing coherence, i.e. minimum or no difference of the pixel attribute value for adjacent pixels, are more reliable than data showing no coherence, in which pixels attribute values show a high heterogeneity in the direct neighborhood of every pixel. Measurement of the structure of spatial data using fragmentation and aggregation metrics hence quantifies the occurrence of large areas of pixels with similar attribute values, which can consequently be used to validate the trends of phenomena observed. In the example, image sections (artificial data) are shown with three attribute values A, B, and C. The observations in the left hand side section are more reliable since adjacent pixels are characterized by identical attribute values. The right hand site section shows only one orthogonal pair with identical attribute values. Note that, using 4-connectivity, the left hand side scene contains only four patches, while the right had side scene 24 patches. The current approach requires sufficient data resolution to enable representation of spatial features by more than one single pixel.

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6. REFERENCES

Allen, T.F.H. and Starr, T.B. 1982. *Hierarchy: Perspectives for Ecological Complexity.* University of Chicago Press, Chicago.

Antrop, M. 2001. The language of landscape ecologists and planners – A comparative content analysis of concepts used in landscape ecology. *Landscape and Urban Planning* 55: 163-173.

Baker, W.L. and Cai, Y. 1992. The r.le programs for multi-scale analysis of landscape structure using the GRASS geographical information system. *Landscape Ecology* 7: 291-302.

Baskent, E.Z. and Jordan, G.A. 1995. Characterizing spatial structure of forest landscapes. *Canadian Journal of Forest Research* 25: 1830-1849.

Benson, B.J. and MacKenzie, M.D. 1995. Effects of sensor spatial resolution on landscape structure parameters. *Landscape Ecology* 10: 113-120.

Bogaert, J. 2003. Lack of agreement on fragmentation metrics blurs correspondence between fragmentation experiments and predicted effects. *Conservation Ecology* 7: www.consecol.org/vol7/iss1/resp6.

Bogaert, J. and Ceulemans, R. Entropy increase of fragmented habitats: a sign of human impact ? *Landscape and Urban Planning*, submitted for publication.

Bogaert, J., Ceulemans, R. and Salvador-Van Eysenrode, D. A decision tree algorithm for detection of spatial processes in landscape transformation. *Environmental Management*, in press.

Bogaert, J. and Impens, I. 1998a. Generating random percolation clusters. *Applied Mathematics and Computation* 91: 197-208.

Bogaert, J. and Impens, I. 1998b. An improvement on area-perimeter ratios for interior-edge evaluation of habitats. In F. Muge, R. C. Pinto and M. Piedade (Eds.), *Proceedings of the 10th Portuguese Conference on Pattern Recognition (RECPAD 98)* (pp. 55-61). APRP-IST, Lisbon.

Bogaert, J., Myneni, R.B. and Knyazikhin, Y. 2002a. A mathematical comment on the formulae for the aggregation index and the shape index. *Landscape Ecology* 17: 87-90.

Bogaert, J. and Rousseau, R. 2001. Spatial aggregation of two-dimensional objects in raster data structures. *Applied Mathematics and Computation* 119: 117-126.

Bogaert, J., Rousseau, R., Van Hecke, P. and Impens, I. 2000a. Alternative area-perimeter ratios for measurement of 2-D shape compactness of habitats. *Applied Mathematics and Computation* 111: 71-85.

Bogaert, J., Salvador-Van Eysenrode, D., Van Hecke, P., Impens, I. and Ceulemans, R. 2001. Land-cover change: quantification metrics for perforation using 2-D gap features. *Acta Biotheoretica* 49: 161-169.

Bogaert, J., Van Hecke, P. and Ceulemans, R. 2002b. The Euler number as an index of spatial integrity of landscapes: evaluation and proposed improvement. *Environmental Management* 29: 673-682.

Bogaert, J., Van Hecke, P. and Impens, I. 1999a. A reference value for the interior-to-edge ratio of isolated habitats. *Acta Biotheoretica* 47: 67-77.

Bogaert, J., Van Hecke, P., Moermans, R. and Impens, I. 1999b. Twist number statistics as an additional measure of habitat perimeter irregularity. *Environmental and Ecological Statistics* 6: 275-290.

Bogaert, J., Van Hecke, P., Salvador-Van Eysenrode, D. and Impens, I. 2000b. Landscape fragmentation assessment using a single measure. *Wildlife Society Bulletin* 28: 875-881.

Bogaert, J., Zhou, L., Tucker, C.J., Myneni, R.B. and Ceulemans, R. 2002c. Evidence for a persistent and extensive greening trend in Eurasia inferred from satellite vegetation index data. *Journal of Geophysical Research* 107/D11: 10.1029/2001JD001075.

Botequilha Leitão, A. and Ahern, J. 2002. Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning* 59: 65-93.

Bribiesca, E. 1997. Measuring the 2-D shape compactness using the contact perimeter. *Computers and Mathematics with Applications* 33: 1-9.

Brokaw, N.V.L. 1982. The definition of tree-fall gap and its effect on measures of forest dynamics. *Biotropica* 14: 158-160.

Burgess, R.L. and Sharpe, D.M. 1981. Introduction. In R.L. Burgess and D.M. Sharpe (Eds.), *Forest Island Dynamics in Man-dominated Landscapes* (pp. 1-5). Springer, New York.

Cain, D. H., Riiters, K. H., and Orvis, K. (1997). A multi-scale analysis of landscape statistics. *Landscape Ecology* 12: 199-212.

Chrisman, N. 1997. *Exploring Geographic Information Systems.* John Wiley & Sons, New York.

Coulson, R.N., Saarenmaa, H., Daugherty, W.C., Rykiel, E.J.Jr., Saunders, M.C., and Fitzgerald, J.W. 1999. A knowledge system environment for ecosystem management. In J.M. Klopatek and R.H. Gardner (Eds.), *Landscape Ecological Analysis – Issues and Applications* (pp. 57-79). Springer, New York.

Curtis, J.T. 1956. The modification of mid-latitude grasslands and forests by man. In W. L. Thomas (Ed.), *Man's Role in Changing the Face of the Earth* (pp. 721-736). University of Chicago Press, Chicago.

Dale, V.H., Offerman, H., Frohn, R. and Gardner, R.H. 1994. Landscape characterization and biodiversity research. In T.J.B. Boyle, and B. Boontawee (Eds.), *Measuring and Monitoring Biodiversity in Tropical and Temperate Forests* (pp. 47-66). Center for International Forestry Research, Bogor.

Davidson, C. 1998. Issues in measuring landscape fragmentation. *Wildlife Society Bulletin* 26: 32-37.

DeMers, M.N. 1997. *Fundamentals of Geographic Information Systems.* John Wiley & Sons, New York.

Farina, A. 1998. *Principles and Methods in Landscape Ecology.* Chapman & Hall, London.

Forman, R.T.T. 1997. *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge.

Forman, R.T.T. and Godron, M. 1986. *Landscape Ecology*. John Wiley & Sons, New York.

Fortin, M.-J. 1999. Spatial statistics in landscape ecology. In J.M. Klopatek and R.H. Gardner (Eds.), *Landscape Ecological Analysis – Issues and Applications* (pp. 253-279). Springer, New York.

Giles, R.H.Jr. and Trani, M.K. 1999. Key elements of landscape pattern measures. *Environmental Management* 23: 477-481.

Groom, M.J. and Schumaker, N.H. 1993. Evaluating landscape change: patterns of worldwide deforestation and local fragmentation. In P.M. Kareiva, J.G. Kingsolver and R.B. Huey (Eds.), *Biotic Interactions and Global Change* (pp. 24-44). Sinauer Associates Inc., Sunderland.

Gustafson, E.J. 1998. Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems* 1: 143-156.

Gustafson, E.J. and Gardner, R.H. 1996. The effect of landscape heterogeneity on the probability of patch colonization. *Ecology* 77: 94-107.

Gustafson, E.J. and Parker, G.R. 1991. An automated method to quantify habitat spatial pattern from satellite images. *Bulletin of the Ecological Society of America* 72: 132.

Gustafson, E.J. and Parker, G.R. 1992. Relationships between land cover proportion and indices of landscape spatial pattern. *Landscape Ecology* 7: 101-110.

Gustafson, E. J. and Parker, G.R. 1994a. Using an index of habitat path proximity for landscape design. *Landscape and Urban Planning* 29: 117-130.

Gustafson, E.J. and Parker, G.R. 1994b. Evaluating spatial pattern of wildlife habitat: a case study of the wild turkey (*Meleagris gallopavo)*. *The American Midland Naturalist* 131: 24-33.

Guttmann, A.J. (1982). On the number of lattice animals embeddable in the square lattice. *Journal of Physics A: Mathematical and General* 15: 1987-1990.

Haines-Young, R. and Chopping, M. 1996. Quantifying landscape structure: a review of landscape indices and their application to forested landscapes. *Progress in Physical Geography* 20: 418-445.

Hargis, C.D., Bissonette, J.A. and David, J.L. 1997.Understanding measures of landscape pattern. In J.A. Bissonette (Ed.), *Wildlife and Landscape Ecology* (pp. 231-261). Springer, New York.

Hargis, C.D., Bissonette, J.A. and David, J.L. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology* 19: 167-186.

He, H.S., DeZonia, B., Mladenoff, D.J. 2000. An aggregation index to quantify spatial patterns of landscapes. *Landscape Ecology* 15: 590-602.

Herzog, F. and Lausch, A. 1999. Prospects and limitations of the application of landscape metrics for landscape monitoring. In M. Maudsley and J. Marshall (Eds.), *Heterogeneity in Landscape Ecology: Pattern and Scale* (pp. 41-50). IALE(UK), Bristol.

Herzog, F., Lausch, A., Müller, E. and Thulke, H.-H. 1999. Das Monitoring von Landschaftsveränderungen mit Landschaftstrukturmaßen – Fallstudie Espenhain. *IÖR-Schriften* 29: 93-109.

Hong, S.-K. 2001. Factors affecting landscape changes in central Korea: cultural disturbance on the forested landscape systems. In I. S. Zonneveld and D. van der Zee (Eds.), *Landscape Ecology Applied in Land Evaluation, Development and Conservation* (pp. 131-147). ITC Publication No. 81, Enschede. The Netherlands.

Hong, S.-K., Kim, S., Cho, K.-H., Kim, J.-E., Kang, S. and Lee, D. 2004. Ecotope mapping for landscape ecological assessment of habitat and ecosystem. *Ecological Research* 19: 131-139.

Jaeger J. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* 15: 115-130.

James, M. 1987. *Pattern Recognition*. BSP Professional Books, Oxford .

Johnston, C.A. 1998. *Geographic Information Systems in Ecology.* Blackwell Science, Oxford.

Krummel, J.R., Gardner, R.H., Sugihara, G., O'Neill, R.V. and Coleman, P.R. 1987. Landscape patterns in a disturbed environment. *Oikos* 48: 321-324.

LaGro, J.Jr. 1991. Assessing patch shape in landscape mosaics. *Photogrammetric Engineering and Remote Sensing* 57: 285-293.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73: 1943-1976.

Li, H. and Reynolds, J.F. 1994. A simulation experiment to quantify spatial heterogeneity in categorical maps. *Ecology* 75: 2446-2455.

Li, H. and Reynolds, J.F. 1995. On definition and quantification of heterogeneity. *Oikos* 73: 280-284.

MacArthur, R. and Wilson, E.O. 1967. *Island Biogeography.* Princeton University Press, Princeton.

Margalef, D.R. 1958. Information theory in ecology. *General Systems* 3: 36-71.

McGarigal, K. and Marks, B.J. 1995. *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure*. Department of Agriculture, Pacific Northwest Research Station, PNW-GTR-351, Oregon.

McGarigal, K. and McComb, W.C. 1995. Relationships between landscape structure and breeding birds in the Oregon Coast Range. *Ecological Monographs* 65: 235-260.

Milne, B.T. 1991. Lessons from applying fractal models to landscape patterns. In M.G. Turner and R.H. Gardner (Eds.), *Quantitative Methods in Landscape Ecology* (pp. 199-235). Springer, New York.

Mladenoff, D.J. and DeZonia, B. 1999. *APACK 2.11 Analysis Software User's Guide (Draft version)*. University of Wisconsin, Forest Landscape Ecology Laboratory, Madison.

Moore, N.W. 1962. The heaths of Dorset and their conservation. *Journal of Ecology* 50: 369-391.

Musik, H.B. and Grover, H.D. 1991. Image textural measures as indices of landscape pattern. In M.G. Turner and R.H. Gardner (Eds.), *Quantitative Methods in Landscape Ecology* (pp. 77-103). Springer, New York.

O'Neill, R.V., Hunsaker, C.T. and Levine, D. 1992. Monitoring challenges and innovative ideas. In D.H. McKenzie, D.E. Hyatt and V.J. McDonald (Eds.), *Ecological Indicators* (pp. 1443-1460). Elsevier, New York.

O'Neill, R.V., Hunsaker, C.T., Timmins, S.P., Jackson, B.L., Jones, K.B., Riiters, K.H. and Wickham, J.D. 1996. Scale problems in reporting landscape pattern at the regional scale. *Landscape Ecology* 11: 169-180.

O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V. and Graham, R.L. 1988. Indices of landscape pattern. *Landscape Ecology* 3: 153-162.

O'Neill, R.V., Riiters, K.H., Wickham, J.D. and Jones, K.B. 1999. Landscape pattern metrics and regional assessment. *Ecosystem Health* 5: 225-233.

Olsen, E.R., Ramsey, R.D. and Winn, D.S. 1993. A modified fractal dimension as a measure of landscape diversity. *Photogrammetric Engineering and Remote Sensing* 59: 1517-1520.

Ricotta, C., Olsen, E.R., Ramsey, R.D. and Winn, D.S. 1997. A generalized non-regression technique for evaluating fractal dimension of raster GIS layers consisting of non-square cells. *Coenoses* 12: 23-26.

Riiters, K.H., O'Neill, R.V., Hunsaker, C.T., Wickham, J.D., Yankee, D.H., Timmins, S.P., Jones, K.B. and Jackson, B.L. 1995. A factor analysis of landscape pattern and structure metrics. *Landscape Ecology* 10: 23-39.

Riiters, K.H., O'Neill, R.V., Wickham, J.D. and Jones, K.B. 1996. A note on contagion indices for landscape analysis. *Landscape Ecology* 11: 197-202.

Riitters, K., Wickham, J., O'Neill, R.V., Jones, B. and Smith, E. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecology* 4: www.consecol.org/vol4/iss2/art3.

Ripple, W.J., Bradshaw, G.A. and Spies, T. A. 1991. Measuring forest landscape patterns in the Cascade Range of Oregon, USA. *Biological Conservation* 57 73-88.

Robinson, G.R., Holt, R.D., Gaines, M.S., Hamburg, S.P., Johnson, M.L., Fitch, H.S. and Martinko, E.A. 1992. Diverse and contrasting effects of habitat fragmentation. *Science* 257: 524-526.

Roseberry, J.L. and Hao, Q. 1995. *HAMS: Habitat Analysis and Modelling System (Version 1.0) – User's Guide and Reference Manual.* Cooperative Wildlife Research Laboratory, Southern Illinois University at Carbondale, Carbondale.

Roseberry, J.L. and Hao, Q. 1996. Interactive computer program for landscape level habitat analysis. *Wildlife Society Bulletin* 24: 340-341.

Rousseau, R. and Van Hecke, P. 1999. Measuring biodiversity. *Acta Biotheoretica* 47: 1-5.

Salvador-Van Eysenrode, D., Bogaert, J. and Impens, I. 1999. Canopy gap morphology determinants in an Amazonian rain forest. *Selbyana* 20: 339-344.

Salvador-Van Eysenrode, D., Bogaert, J., Van Hecke, P. and Impens, I. 1998. Influence of tree-fall orientation on canopy gap shape in an Ecuadorian rain forest. *Journal of Tropical Ecology* 14: 865-869.

Salvador-Van Eysenrode, D., Bogaert, J., Van Hecke, P. and Impens, I. 2000. Forest canopy perforation in time and space in Amazonian Ecuador. *Acta Oecologica* 21: 285-291.

Scheiner, S.M. 1992. Measuring pattern diversity. *Ecology* 73: 1860-1867.

Schumaker, N.H. 1996. Using landscape indices to predict habitat connectivity. *Ecology* 77: 1210-1225.

Sharpe, D.M., Stearns, F.W., Burgess, R.L. and Johnson, W.C. 1981. Spatio-temporal patterns of forest ecosystems in man-dominated landscapes of the Eastern United States. In S.P. Tjallingii and A.A. de Veer (Eds.), *Perspectives in Landscape Ecology: Contributions to Research, Planning and Management of our Environment* (pp. 109-116). Pudoc, Veldhoven.

Stauffer, D. 1985. *Introduction to Percolation Theory*. Taylor & Francis, London.

Stine, P.A. and Hunsaker, C. T. 2001. An introduction to uncertainty issues for spatial data used in ecological applications. In C. T. Hunsaker, M. Goodchild, M. A. Friedl and T. J. Case (Eds.), *Spatial Uncertainty in Ecology – Implications for Remote Sensing and GIS Applications* (pp. 91-107). Springer, New York.

Turner, M.G. (1989). Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* 20: 171-197.

Turner, M.G. 1990a. Landscape changes in nine rural counties in Georgia. *Photogrammetric Engineering and Remote Sensing* 56: 379-386.

Turner, M.G. 1990b. Spatial and temporal analysis of landscape patterns. *Landscape Ecology* 4: 21-30.

Turner, M.G., O'Neill, R.V., Gardner, R.H. and Milne, B.T. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* 3: 153-162.

Turner, M.G. and Ruscher, C.L. 1988. Changes in landscape patterns in Georgia, USA. *Landscape Ecology* 1: 241-251.

Urban, D.L., O'Neill, R.V. and Shugart, H.Jr. 1987. Landscape ecology: a hierarchical perspective can help scientists understand spatial patterns. *BioScience* 37: 119-127.

Webb, N.R. and Haskins, L.E. 1980. An ecological survey of heath lands in the Poole Basin, Dorset, England, in 1978. *Biological Conservation* 17: 281-296.

Weiner, J. and Solbrig, O.T. 1984. The meaning and measurement of size hierarchies in plant populations. *Oecologia* 61: 334-336.

Wickham, J.D. and Riiters, K.H. 1995. Sensitivity of landscape metrics to pixel size. *International Journal of Remote Sensing* 16: 3585-3594.

Wickham, J.D., Riiters, K.H., O'Neill, R.V., Jones, K.B. and Wade, T.G. 1996. Landscape contagion in raster and vector environments. *International Journal of Geographical Information Systems* 10: 891-899.

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PART II

BIOLOGICAL RESPONSE IN ENVIRONMENTAL CHANGES: PATTERN AND PROCESS

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CHAPTER 9

BIOLOGICAL RICHNESS OF THE ASIAN TIDAL FLATS AND ITS CRISIS BY HUMAN IMPACTS

1. INTRODUCTION

The great biological richness of the Asian coastal shallow waters including estuaries and intertidal flats seems to be underestimated probably due to its simple and colourless appearance and the delay of the basic studies. Human impacts such as water pollution have damaged the coastal environments. For example, species number and biomass of benthic invertebrates were rapidly decreased in late 1960s or early 1970s in Qingdao in the inner part of Yellow Sea, probably caused by the discharge of pollutants into the bay from many chemical plants (Wu *et al*. 1992). At the same period, the heavy mercury pollutions causing the severe injury of human health of many local people through food chain occurred in Japanese coasts (*i.e.,* Minamata disease, Ui 1992, Harada 1995). Similarly, in Onsan, South Korean, a disease related with heavy industrial pollution occurred in 1980s (*i.e*., Onsan disease), and the potential biological effects associated with some organic chemicals seem to be still under exposure in this area (Koh *et al*. 2002a).

Another aspect of recent serious human impacts is the large-scale of reclamation project in shallow coastal zones, especially in intertidal flats of the Asian countries. We feel anxious that the whole original biodiversity and ecological process in these areas might be lost by the serious human impacts in relation to the rapid developments in the Asian countries before we know them. The experiences of 'Sihwa Project' in Korea and 'Isahaya Project' in Japan would be representative examples. Currently in South Korea, huge reclamation projects such as the 'Saemangeum Project' modifying 400 km^2 of tidal flat area into farmland are rigidly in progress although their serious impacts are clearly expected.

In the present paper, estuaries and intertidal flats in Ariake Sea, western Kyushu, Japan, and in West Sea, the eastern part of Yellow Sea, western Korea are focused (Fig. 1). We review the environmental characteristics, biodiversity, bioproductivity, and influence of the recent huge reclamation projects in these areas, though we have no complete fauna list there because of the delay of the taxonomic studies on macro benthic invertebrates and meiofauna. Particularly, in South Korea, the studies on

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certain benthic organisms are very delayed due to the less attention and scientific effort.

2. GENERAL ASPECTS OF ARIAKE SEA, JAPAN AND KOREAN COAST OF THE YELLOW SEA

The West Sea, the Korean west coast of the Yellow Sea, show unique environmental characteristics such as the greatest tidal range (the vertical distance between low and high tide marks, Fig. 2) and the largest extent of tidal flats along the coastal lines and riverine estuaries. The Ariake Sea in western Kyushu, Japan has similar environmental characteristics as “a miniature of the Yellow Sea”. The tidal amplitudes in these shallow semi-enclosed bays are enhanced by a resonance effect (co-oscillation) between the outer oceanic tidal oscillation and the inner free oscillation which is determined by the size of the bays (Unoki 2003a), and consequently much larger than those in the neighbouring sea.

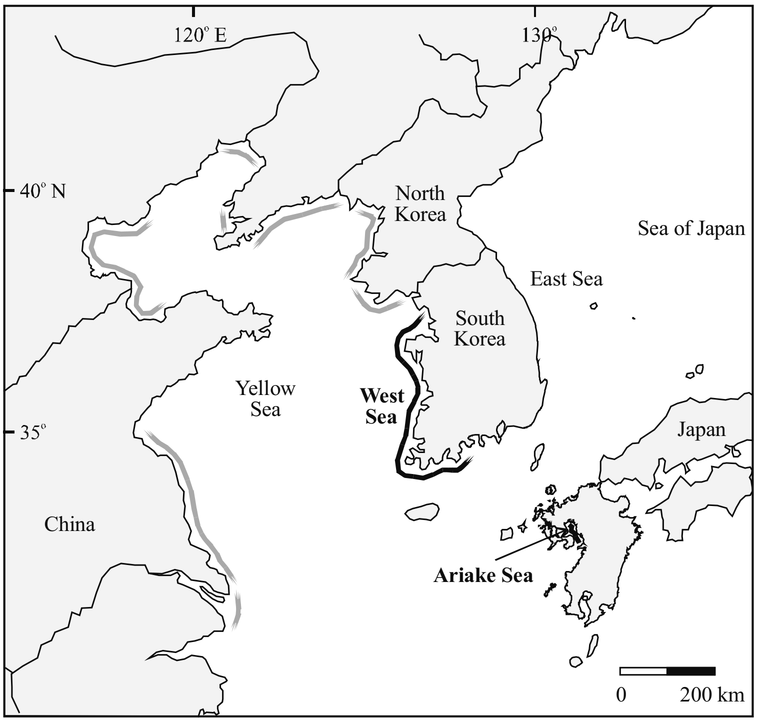

Figure 1. Map showing the location of the West Sea, the eastern part of the Yellow Sea and the Ariake Sea in Kyushu, Japan. Black lines indicate the tidal flats on the coast of the West Sea (tidal flat area: 2,880 km^2) and the Ariake Sea (tidal flat area: 200 km^2) and gray lines depict the tidal flats of the North Korea and China. Modified from Barter (2002).

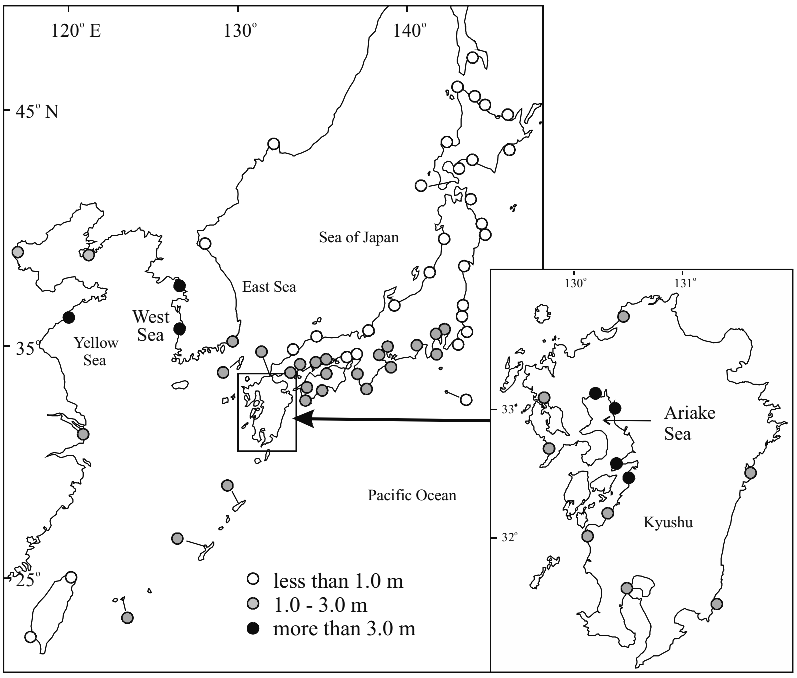

Figure 2. Mean tidal range (vertical distance between mean low and high tide marks) in spring tides in Japan and neighbouring countries. After Sato and Takita (2000).

The tidal range in western Korea is the greatest in Asia (maximum: more than 9 m), and that in Ariake Sea is the greatest in Japan (maximum: more than 6 m) (Koh 1997, Sato and Takita 2000). It is also important to form the huge tidal flats that large rivers flow into the semi-enclosed coastal areas and supply a large amount of muddy and sandy sediments there together with freshwater and nutrients. Thus, the huge tidal flats and estuaries develop on the coasts of the Yellow Sea and Ariake Sea.

In these areas, fishery productivity is very high due to high primary production of benthic microalgae and short food web to fishery products: Fisheries catch in the Ariake Sea (82 ton/km^2/year in 1979) was much larger than those in the Seto Inland Sea, Japan (22 ton/km^2/year), Chesapeake Bay, USA (7 ton/km^2/year) and North Sea (5 ton/km^2/year) (Yanagi 2002). The estuaries of rivers and shallow coastal areas are also important as nursery grounds for many fishes and crustaceans (Takita 2000).

The benthic fauna and salt-marsh flora in the Ariake Sea are similar to those in the Yellow Sea (Sugano 1981, Sato and Takita 2000). This similarity is probably caused by not only the environmental similarity but also a geohistorical relationship between them: it seemed that the shallow coastal fauna and flora were located in a presumable large semi-enclosed bay in the last glacial period ($1.5 - 1.8 \times 10^4$ years ago) when the Japanese land was connected to the continental proper. Subsequently,

the common ancestors of benthic organisms were split into the continental population and the Japanese one after the Japanese land was separated from the continental proper by the formation of Straits of Tsushima (Shimoyama 2000).

3. ARIAKE SEA, JAPAN

3.1. Unique Environments

Ariake Sea (1,700 km^2 in area) in western Kyushu is an unusual bay in Japan, as characterized by the greatest tidal range (more than 6 m in maximum in spring tides) and the largest extent of tidal flats (about 200 km^2) in Japan. The Chikugo River (the largest river in Kyushu) flows into the innermost NE part of Ariake Sea, supplying a large amount of freshwater, nutrients and sediment particles. The muddy tidal flats develop mainly in the innermost part. The sandy tidal flats are extended rather to the eastern part (*i.e*., the coast of Kumamoto Prefecture).

The strong tidal current severely suspends fine muddy particles from bottom sediments at each flooding and ebbing time, and floats detritus and nutrients associated in it especially, in the innermost part of the Ariake Sea. The floating detritus play an important role for the high productivity as an effective source of food to macrobenthos (Sato and Takita 2000), though it makes "dirty" appearance in colour of seawater with low transparency.

3.2. Unique Fauna

A unique distributional pattern is known for more than 20 fishes and invertebrates, which are designated as Ariake Sea-indigenous (or continental relict) species (Sato and Takita 2000). For example, the distribution of an ocypodid crab, *Ilyoplax deschampsi* is restricted to the extremely muddy tidal flats in the innermost part of the Ariake Sea and Yellow Sea, while a closely related species, *I. pusilla* distribute in a wide range in Japan (Wada *et al*. 1992, Kosuge 2000) (Fig. 3). A similar distributional pattern is known in a catadromous fish, *Trachidermus fasciatus*. This species is restricted to rivers within Yellow Sea, and apart from that, rivers within the inner Ariake Sea. For this fish, the tidal flats are nursery grounds. Namely, the mature adults spawn egg masses in dead oyster or other bivalve shells (Onikura 2000), and after living in the shallow coastal area during the early development stage, the juveniles come up the rivers, and adults live in freshwater. For these species, the Japanese populations distribute only (at least at present) in tidal flats or estuaries in the innermost part of the Ariake Sea, with no or few exceptions, and their closely related populations or species distribute in Korean and Chinese coasts of the Yellow Sea. However, the most important place for the unique fauna and flora was recently lost by the Isahaya Bay project (see below).

The extremely restricted distribution of the Ariake Sea-indigenous species is very unique, because marine or estuarine organisms are usually dispersible. Those

limited distributions may be caused partially by their narrow habitat-preference related to the unique environment of Ariake Sea. But, at least for some cases, there are evidences showing that the distribution range in Japan is rapidly reduced due to the human impacts during the recent 100 years (see below).

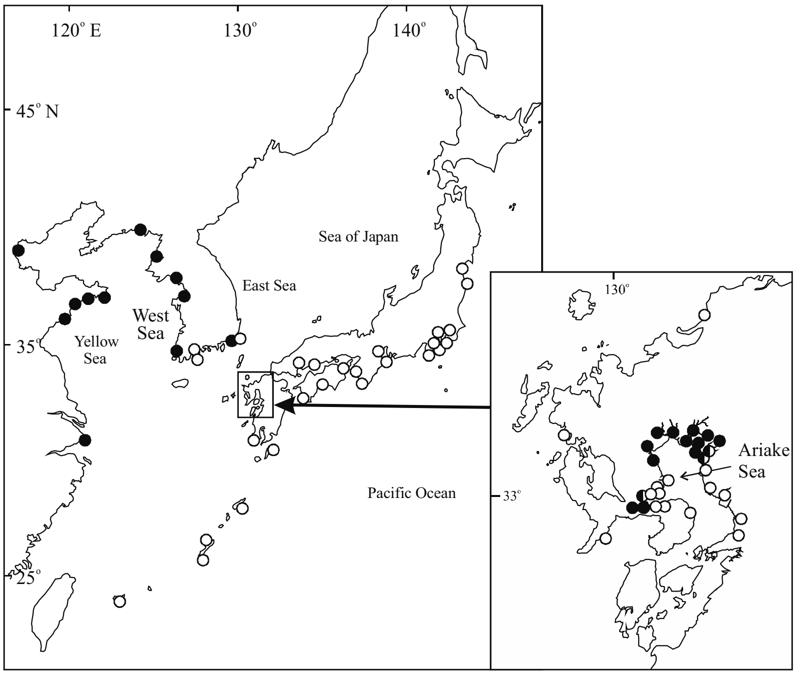

Figure 3. Distribution of two ocypodid crabs, Ilyoplax deschampsi (solid circle) and I. pusilla (open circle). Half-solid circles indicate occurrence of both species. After Kosuge (2000).

3.3. Recent Reclamation Project in Isahaya Bay and Its Impacts

Isahaya Bay is located in the inner part of Ariake Sea. The inner part of Isahaya Bay was closed by the 7 km-long dike in 1997 (Fig. 4). Total closed area is 3,550 ha (36 km^2). The original tidal flat was changed to a dry land in the upper part and to a freshwater pond as a regulating reservoir in the lower part. The dried upper part was planed for the agriculture land. The original tidal flat and gradual brackish-waters along the former creeks and tidal channels were lost by the dike construction. Recent data shows that this project may bring deleterious effects in the whole Ariake Sea even outside the dike in various aspects (*i.e.*, frequent occurrence of red tides, rapid reduction of benthic fauna and fisheries catch) (Azuma 2000, 2001, 2002, Sato *et al.* 2001, Unoki 2002a, 2003a, b).

A serious problem is the eutrophication within the regulating reservoir. Mean concentrations of nutrients in the reservoir showed marked increasing after the

enclosure of Isahaya Bay (Sato *et al*. 2001). The freshwater in the reservoir became nutrient rich by the loss of the tidal-flat ecosystem, which had functioned for a removal of nutrients before the dike construction.

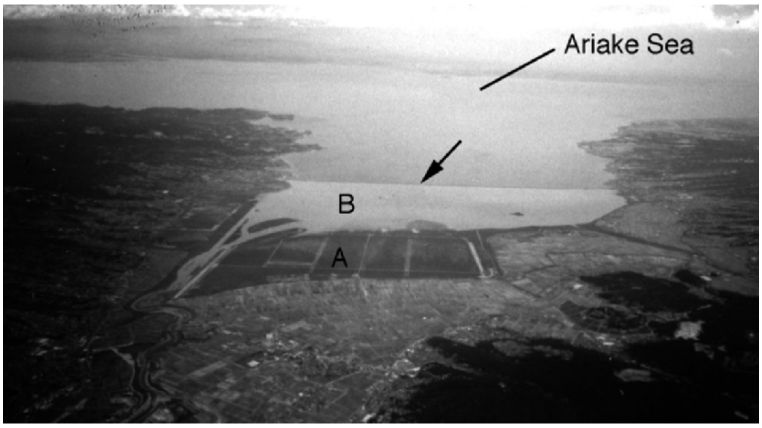

Figure 4. The Isahaya reclamation project in progress in Ariake Sea in Kyushu, Japan in July 2000. The inner part of Isahaya Bay was closed by the 7 km long dike (arrow) in 1997. The original tidal flats were changed to a dry land in the upper part (A) and to a freshwater pond (the regulating reservoir) in the lower part (B).

The freshwater is intermittently drained into the Ariake Sea through the two floodgates (northern one 200 m wide and southern one 50 m wide) on the 7 km dike during low-tide (more than 7×10^7 m^3/day in maximum), floats over the seawater outside the dike due to its lower specific gravity, and adds the nutrients to the surface of the inner part of the Ariake Sea. The load of nutrients into the Ariake Sea during the drainage was estimated to be 30 ton/day for nitrogen, 5 ton /day for phosphorus, and 158 ton/day for silica (Sato *et al*. 2001).

Another serious effect by the Isahaya project is the decay of the tidal amplitude and tidal currents in the inner part of Ariake Sea. Sato and Takita (2000) found the remarkable decay of tidal amplitudes in the innermost part of the Ariake Sea since 1989 when the Isahaya project began. Unoki (2002a, 2003a, b) supported this fact and showed that about 50 % decreasing of M2 constituent (major factor of the total tidal amplitude) is attributed to the decay of the co-oscillating tide, which was caused by the reduction of the Ariake Sea due to the reclamation of the Isahaya Project, though the less gradual decay of tidal amplitudes has been observed widely in Japanese coasts since around 1980. Consequently, the tidal currents have been markedly decreased since the dike construction of the Isahaya project was completed: 10 – 90 % of the original tidal currents was reduced around the Isahaya Bay in the innermost part of Ariake Sea (Unoki 2002a, 2003a). The decay of the tidal current seems to subsequently stagnate the water flow of the innermost part of Ariake Sea. The consequent restriction of water exchange in the inner part of Ariake

Sea may accelerate the unusual occurrences of the plankton blooming and hypoxia of sediment and seawater, making the deteriorated effects on benthic fauna and fishery (Azuma 2000, 2001, 2002, Kawaguchi *et al*. 2002, Sato *et al*. 2001, Tsutsumi *et al*. 2003). In December 2001, the committee of Japanese Ministry of Agriculture, Fishery and Forestry proposed a long-term examination after recovering the tidal flat ecosystem of the Isahaya Bay. But, Japanese government has announced that the project should be proceeded further to complete as planed previously.

3.4. Other Human Impacts

Sand has been taken by digging from the shallow sea floor in Ariake Sea to be used for the dike construction of the Isahaya reclamation project (Azuma 2000, 2001) or for covering the farm areas of a clam, *Tapes (Ruditapes) philippinarum* in the middle and inner parts of Ariake Sea. This human activity destroys the natural environments for the coarse-sand benthic community, which includes a rare Japanese population of *Branchiostoma belcheri* (Chordata) (Henmi *et al.* 2000), remaining deep depressions in the bottom. The depressions seem to accelerate hypoxia of bottom water (Azuma 2000).

Many dams have been constructed in upper or lower reaches of rivers flowing into Ariake Sea. In general, the amount and current speed of out-flowing freshwater are reduced at river-mouth by dam construction. This may cause the decreasing water exchange between the bottom and surface in estuaries, resulting in deteriorate effects such as hypoxia of bottom water (Unoki 2002b). Sand supply from rivers into the coastal areas is also reduced by dam construction (Unoki 2002b). The reduced sand supply seems to cause the shrinking of sandy tidal flats.

3.5. Invasion of Alien Species

As for molluscs, which are relatively well surveyed, 6 alien species have been recorded from the Ariake Sea (*Crepidula* (*C.*) *onyx*, *Mytilus galloprovincialis*, *Meretrix petechialis*, *Potamocorbula laevis*, *Stenothyra* sp. and *Nassarius* (*Zeuxis*) *sinarus*) (Sato 2000, Kikuchi 2000, Tamaki *et al.* 2002). The native coastal ecosystems and biodiversity may be damaged by these alien species. For example, a native edible clam, *Meretrix lusoria* living in sandy tidal flats, has been replaced with a congeneric alien species *M. petechialis* that was introduced from Korea or China.

The invasion of the alien species may be related to various human impacts. Previously, native populations of the edible bivalves (*e.g*., *Tapes (Ruditapes) philippinarum, Meretrix lusoria*, *Sinonovacula constricta*) were harvested as major fishery products in tidal flats of the Ariake Sea. However, the fishery catch of the economically valuable bivalves drastically decreased since around 1980 (Kikuchi 2000, Ishii and Sekiguchi 2002, Nakahara and Nasu 2002). Consequently, a large numbers of bivalves caught from Korea or China (*i.e*., foreign population or species different from Japanese ones) have been imported to Japan, and often released to

outdoors directly on tidal flats in Ariake Sea and other coastal areas. The artificial transportation of the foreign populations seems to increase the chances of invasion of alien species of not only the bivalve itself but also smaller companions: Invasion of two alien gastropods, *Stenothyra* sp. and *Nassarius* (*Zeuxis*) *sinarus* was recently found in the inner part of Ariake Sea (Tamaki *et al*. 2002).

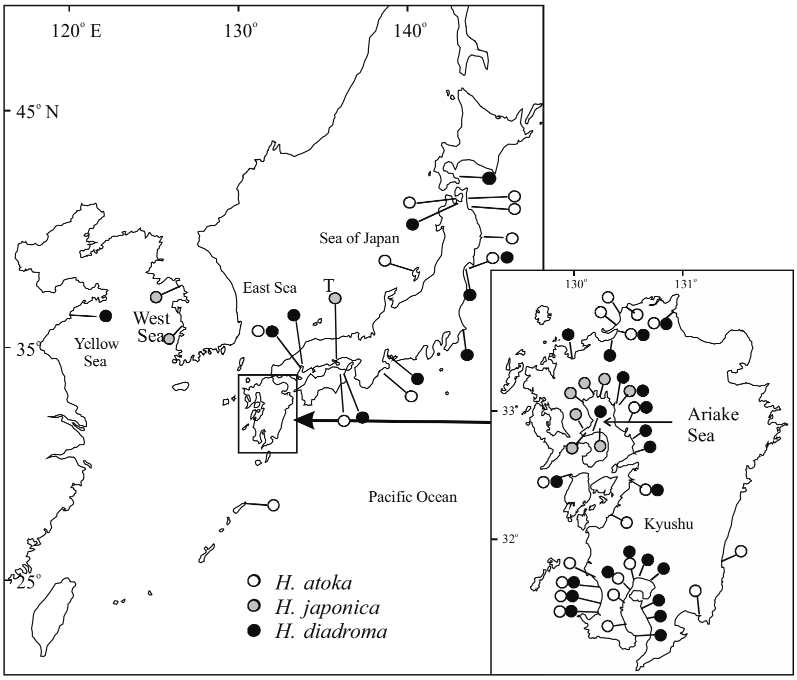

Figure 5. Distribution of 3 Hediste *species,* H. japonica, H. diadroma *and* H. atoka*. The habitat of* H. japonica *in the inner part of Kojima Bay (T: type locality of this species) in Seto Inland Sea was lost in 1959 due to the dike construction similar to the Isahaya project in Ariake Sea. Based on M. Sato (2000) and Sato and Nakashima (2003).*

Tamaki *et al*. (2002) suggested that the alien gastropods seemed to be recently introduced together with the Korean population of *Sinonovacula constricta*, which has been transplanted into the inner part of Ariake Sea since 1993 (S. Sato 2000).

The foreign sand, which has been transported to Japanese coasts to create and enhance artificial beaches etc., may also increase the chances for invasion of alien species (Domoto 2001). In any cases, the successful invasion of these alien species may be assisted by the collapse of native populations in the benthic community in Ariake Sea, where various human impacts damaged the natural environments.

3.6. Importance of Ariake Sea as a Final Habitat of Endangered Species

The genus Hediste (Polychaeta, Annelida) is one of the most dominant macrobenthos in estuarine tidal flats in Asia and other North Temperate Zone. Therefore, it is ecologically important species group. Previously, 3 Hediste species are known from eastern Asia (Sato and Nakashima 2003): H. diadroma and H. atoka widely distribute in Japan, while H. japonica inhabits only in the inner part of the Ariake Sea and the Korean coasts of Yellow Sea at present (Fig. 5).

Figure 6. Mass deaths of the bivalve Tagillarca granosa *inhabiting the muddy tidal flats in the inner part of Isahaya Bay in Ariake Sea in August 1997 (4 months after enclosure of the bay by the dike construction). The maximum density of this species was more than 70 individuals /m^2 (S. Sato 2000). Photograph by K. Tominaga (After Sato and Takita 2000).*

The distribution range of *H. japonica* is similar to that of the other Ariake Sea-indigenous species as described above.

The extremely restricted distribution of *H. japonica* in Japan seems to be caused by the recent human impacts. Sato and Nakashima (2003) could examine the type material of this species, which was recently discovered, and confirmed that it was collected from Kojima Bay, Seto Inland Sea in 1906 (about 100 years ago) (Izuka 1908), though the tidal flats of the type locality were lost in 1959 to reclamation. Therefore, the distribution of *H. japonica* seems to have been formerly extended to the wider areas in Japan, and recently reduced into the inner part of the Ariake Sea. In Japan, about half of the tidal flats have already disappeared, mostly during the

past 100 years, because of artificial reclamation especially in enclosed coastal areas such as Seto Inland Sea and Tokyo Bay.

At present, the inner part of the Ariake Sea is the only known habitat for *H. japonica* remaining in Japan (Fig. 5). A recent reclamation project in Isahaya Bay in the inner part of the Ariake Sea, however, caused the loss of a muddy shallow area of about 36 km^2, including the most important habitat for *H. japonica* (see above). The Korean tidal flats, where *H. japonica* inhabits, are now damaged by reclamation on an even larger scale (see below). Thus, *H. japonica* seems to be endangered to extinction.

A reduction in the distribution range of muddy shallow-water fauna in Japan is well documented in some bivalves such as *Tagillarca granosa*, for which many fossil records are available. *T. granosa* is one of the most common species found in shell mounds around Tokyo, central Japan (Morse 1879). The living specimens of this species were recorded in many bays, in western Japan until 100 years ago (S. Sato 2000). At present, however, the distribution of Japanese population of this species is limited probably only to the inner part of the Ariake Sea, probably due to recent human impacts to muddy shallow habitats (Fig. 6).

4. COASTS OF WEST SEA IN KOREA

4.1. Geographical characteristics of huge tidal flats

The Korean and Chinese coasts of the Yellow Sea show unique environmental characteristics such as the greatest tidal range and the gentle bottom slope following the largest extent of tidal flats (Fig. 1 and 2). Along the west coast of Korea (West Sea), tidal flats are well developed to c.a. 10 km wide in many places and the total area is estimated at about 2,880 km^2 (Fig. 1 and 7).

The modern tidal flats on the west coast of Korea were formed during the recent Holocene (8,000 years ago – present) by the large supply of sediment from the rivers of surroundings. The tidal range in spring tides varied along the coastal line, due to the geomorphological characteristics of semi-closed system, increasing from 4 m near Mokpo in the south to 9 m at Incheon approaching to the north (Fig. 2).

The Korean tidal flats should also be assigned into mud, mixed, and sand flats from upper to lower intertidal zones. The mud flats had largely been decayed due to the embankment for the rice field during the Japanese colonial era, especially from 1920 to 1940. Salt marshes developed between the mud flats and the lands are rarely found therefore, whereas the mixed flats are in large scale and begin from the exposed coastline directly. One of the main fisheries is shellfish farming on the mixed flats. The fishery itself is not a commercial or mechanica but a hand catch, and considered to be sustainable. We will show the recent awful projects by two major examples, *i.e.*, ‘Sihwa Project’ and ‘Saemangeum Project’ in the below.

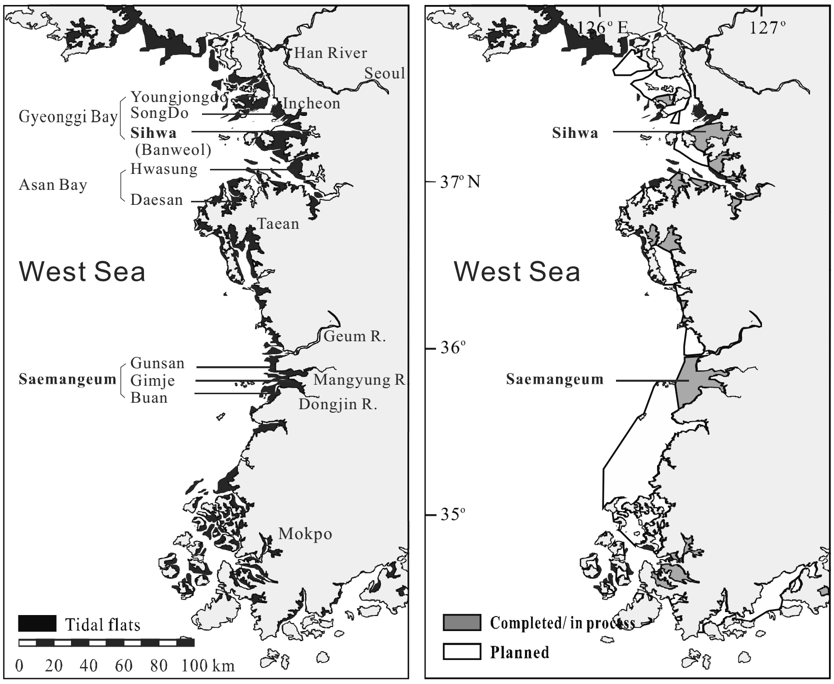

Figure 7. Map showing the Korean tidal flats developed along the west coast in ria type (left; Koh 2001). The area lost by the reclamation in Korea during the last 100 years is ca 1,800 km^2. Central government plans to dike also in the offshore area (right; RDC 1996).

4.2. Sihwa Reclamation Project and Its Impacts

Sihwa area (170 km^2) was a wedge-shaped bay recessed into SE part of the Gyeonggi Bay, Korea (Fig. 7 and 8). The tidal flat has been turning to a dry land and the deep channel area of ca 10 m depth to an artificial lake after embankment of the 12.7 km-long dike which was completed in 1994 (Fig. 7 and 8). Establishment of the rice field after the reclamation was the purpose of the Sihwa project and thereby, an artificial lake (Lake Sihwa) in the channel area was planned to maintain and supply freshwater for an agricultural use in the rice field to be reclaimed on the former tidal flat. However, water in the lake was degraded during the period for sweetening of water. The lake had received freshwater from the creeks of surroundings and discharged the overflows through the floodgate during the ebb tide. As expected, the degradation of water quality occurred already during this process of desalination. In May 1996, a

public air wave TV, SBS, reported that the water being discharged through the floodgate was in black colour by showing an airborne picture and thereafter, the water pollution in the Lake Sihwa became a hot issue both in the media and public society.

Several studies showed that how worse the lake water was degraded: For example, COD concentration in the Lake Sihwa was increased from 2 mg/L in 1994 to 12 mg/L in 2000 (MOMAF, 2001) and the highest concentration of alkylphenols up to 1,820 ng/g (dry weight) was found in bottom sediment of the Lake Sihwa in 1998 (Khim *et al* 1999). Again drastic elevation of chlorophyll *a* concentration up to 700 ug/L in 1996 just after the media report indicated unusual blooming of phytoplankton due to an eutrophication. Satellite image (March, 1999) of the Lake Sihwa apparently showed that lake water turned to a black colour suggesting an extreme eutrophication in this case (Fig. 8).

The central government had renewed the lake water with several million tons of seawater daily by a regular opening of the floodgate since July 1997, however, the water quality inside of the Lake Sihwa was not improved up to a desired level.

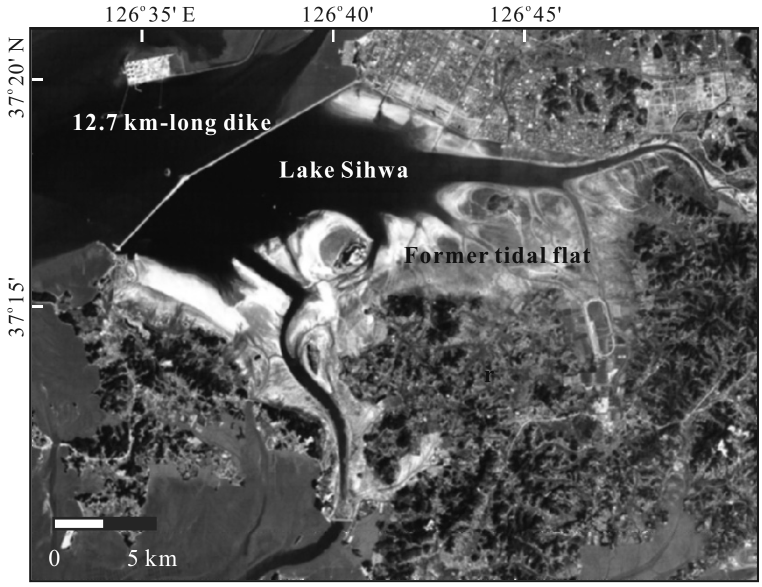

Figure 8. Satellite image (March 1999) showing apparent water pollution in Lake Sihwa (black colour) and dried former tidal flats (white colour).

Finally, in February 2001, the government gave up to keep the Lake Sihwa as a freshwater reservoir. At present, the Lake Sihwa remains as a seawater lake with the floodgate opened permanently. The aim of the land reclamation of 170 km^2 by the governmental project is not achieved due to the failure in freshwater supply from the reservoir and the former tidal flat remained to be dry and deteriorated.

Besides the degradation of lake water, the deleterious effect was shown also on the sediment fauna of subtidal zone. The study of benthic community by Shin *et al*. (1989) would be a good reference for an overview and a description of faunal changes in this region, because it covered the coastal region of Gyeonggi Bay in general, including offshore of Sihwa, and reported the species association in various sediment bottoms before the dike construction, namely during 1987 - 88; the sediment fauna comprised of a total of 87 species (64.7, 17.4, and 15.2 % for polychaetes, molluscs, and crustaceans, respectively), showing the mean density of 550 ind./m^2. However, the study area included mainly offshore channels, so the data was not comparable directly to the channel area of the Lake Sihwa.

In the channel of Sihwa itself, KORDI (1981) reported more than 100 species of benthic invertebrates in 1981. After the dike construction, however, the species number has been reduced to 25 and 8 in 1996 and 1997, respectively (Ryu *et al*. 1997, KORDI 1999). After starting a renewal of seawater in the Lake Sihwa by regular flushing with seawater of offshore from March 1997, sediment fauna seemed to be recovered gradually considering an increasing number of species. For example, in 2000, the benthic macrofauna showed a high number of species of 89 (41.6, 22.5, 20.2 and 15.7 % for polychaetes, molluscs, crustaceans, and others, respectively) (MOMAF 2001).

Another interesting feature is that the dominant species has been changed according to the dike construction. A polychaete *Polydora ligni* increased drastically after 1 year from the dike completion (Fig. 9) (Ryu *et al*. 1997). This species never occurred in Gyeonggi bay including Sihwa area before, but became dominant in the Lake Sihwa. This species seems to be associated with a degradation of sediment by high amount of organic rich materials (Pearson and Rosenberg 1978). During 1995 - 96, the dominant species had been replaced with another polychaete *Pseudopolydora kempi,* and finally to *P. ligni* again. *P. kempi* which is also commonly found in the polluted area showed high occurrence in the Lake Sihwa supporting a deterioration of benthic habitat (Ryu *et al*. 1997).

The density of polychaete populations in the Lake Sihwa became much higher after the dike construction. The high density of *P. ligni* in the beginning of 1995 was unusual (ca 2,000 - 3,000 ind./ m^2). Moreover, the density of this species in March 1998, namely 4 years after the dike construction, was extremely great (36,000 ind./ m^2).

In conclusion, the habitat degradation seems to be reflected in the species diversity and density of benthic fauna; low species diversity with high population density was clearly observed during the course of time since the dike construction in 1994.

For the fauna on the intertidal flats, three reports could be referred for a comparison before and after the dike construction (Koh and Shin 1988, Shin *et al.* 1989, Lee and Koh 1994). Shin *et al*. (1989) extended the grab sampling even to the intertidal flats during submergence along the Gyeonggi Bay, and reported the dominant species of *Nepthys californiensis, Mactra veneriformis* and *Hinia festiva.*

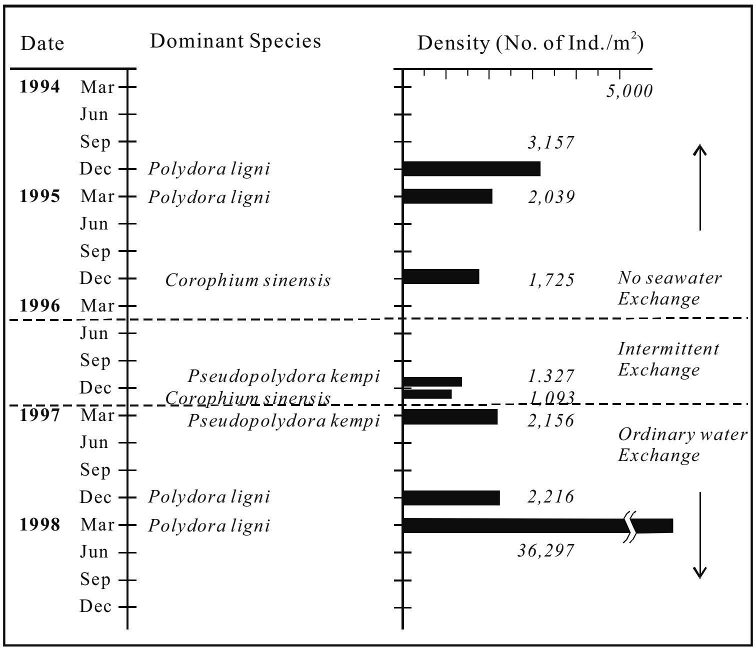

Figure 9. The occurrence of Polydora ligni *as a dominant species over the period of 1994 to 1998 in the Lake Sihwa. During 1995 - 1996, however,* Pseudopolydora kempi.*and* Corophium sinensis *had been dominated. Based on Ryu et al. (1997) and KORDI (1999).*

By sampling with shovel along the three transects directly on the Sihwa tidal flats during 1984-85, Koh and Shin (1988) described three type of species associations in an aspect of zonation from the higher to lower intertidal zones; *Helice*, *Macro-phthalmus* and *Laonome-Potamocorbula* zone. The dominance of those crabs and suspension feeders from high-mid to lower intertidal zones, respectively, was characteristic to the Sihwa tidal flats. Lee and Koh (1994) examined again the middle transect during summer of 1985 in terms of biogenic sedimentary traces and found high density of residence holes of crabs and polychaetes of *Perinereis aibuhitensis* and *Periserula leucophyryna*. The Sihwa tidal flats were muddy (mud contents: ca 30 - 50 %, Koh and Shin 1988), supplying preferred habitat for hole burrowing crabs and polychaetes.

During revisiting the Sihwa tidal flats in 2000, the second author found the razor clams of *Sinonovacula constricta* widely dispersed in death (Fig. 10). By sampling of hand digging during the former study, this clam was seldom caught and not recorded as a dominant species, therefore. However, the photograph of Fig. 10 demonstrates an enormously high density of the clam with a wide range of distribution. This species was typically distributed in the muddy flats of Namyang Bay and Saemangeum area (as mentioned below).

Figure 10. The razor clam, Sinonovacula constricta, was not reported as the main fishery in Sihwa area, but found stuck widely on the former tidal flat in a large amount in 2000. Photograph by Chul-Hwan Koh in 2000.

4.3. Saemangeum Project and Its Impacts

The Saemangeum area is located in an estuary near cities of Gunsan, Buan, and Gimje on the west coast of Korea (Fig. 7). Two big rivers, Mangyung and Dongjin rivers, flow into this area, supplying a large amount of nutrient-rich freshwater (total 6.4×10^6 ton/yr). Intertidal flats in the Saemangeum area are the largest in South Korea with a broadness of 20 km at its central site. The tidal range is 3 – 6 m (average: 4 m), and the tidal current velocity is 0.8 – 2.4 m/sec at flood and ebb tides. Various bottom types with muddy, mixed or sandy sediments develop from the mouth of rivers to outer flats, providing various habitats for benthic fauna and flora there. The ecological importance of the Saemangeum area seems to be of great considering both a large scale of natural habitats for living organisms from benthic fauna and flora to waterfowl and huge grounds for fishery.

An and Koh (1992) demonstrated the distribution and abundance of macrobenthic invertebrates along the 8 transect lines on the intertidal flats in this area in 1988 (before the launch of dike construction). Totally, 64 species were found by hand digging up to 30 cm sediment depth with mean density of 1,225 ind./m^2.

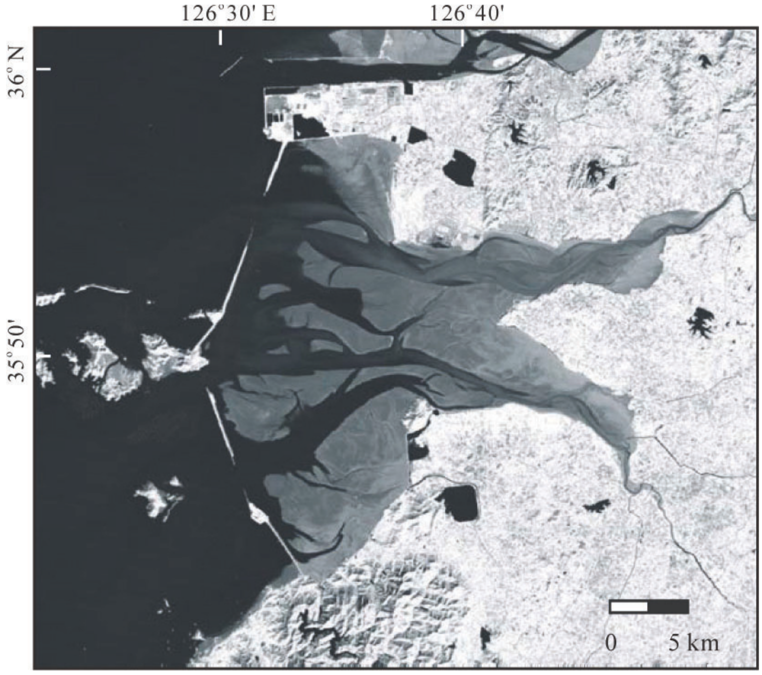

Figure 11. Satellite image (Feb 2002) showing the tidal flats of Saemangeum area and the dike building proceeded since 1991.

The dominant species occupied more than 95.5 % of total occurrence were *Laternula* cf. *limicola* (71 %), *Umbonium thomasi* (22 %), and *Lingula unguis* (2.6 %). The distribution of the benthic macrofauna was closely related with the height (elevation) of the site or the duration of tidal exposure. The *Perinereis* association was characteristic to the most exposed area, the upper intertidal zone, while the *Macrophthalmus* and the *Bullacta-Mactra-Umbonium* association were found along the decreasing of exposure duration, directing to the middle intertidal zone.

At the same time, another study focused on the benthic community mainly in the subtidal areas of Mangyung, Dongjin, and Geum estuaries and the nearby coastal region (Choi and Koh 1994). A total of 61 species were collected from 39 sites with a mean density of 722 ind./m^2. A unique distribution of the subtidal populations was observed from estuaries in Mangyung and Dongjin rivers to offshore areas. For example, *Potamocorbula amurensis*, *Nephtys californiensis* were dominated occupying over 80 % of total in the estuaries, while *Mactra chinensis*, *Magelona japonica*, and *Owenia fusiformis* were relatively dominated in the offshore region. A living fossil brachiopod species, *L. unguis* was widely found near Gunsan and Gimje, indicating a unique benthic habitat for Saemangeum tidal flats.

A series of comparative studies on macrobenthic community on eight tidal flats along the west coast of Korea from 1984 showed the highest density of 3,783 ind./m^2 in the Saemangeum area (Koh 1997). A high biodiversity of microphytobenthos in the same area was suggested by the occurrence of 371 species of benthic diatom collected from 60 sites there in 1988 (Oh and Koh 1995).

A huge reclamation project is now proceeding. The total of 400 km^2 of shallow coastal area will be lost by a 34 km-long dike from the Saemangeum reclamation project (Fig. 11). This project has been initiated by the dike construction at first in 1991. As for the dike construction, the pouring stones and sands into the channel bottom have been progressed to about 70 % of the total dike length planned. The situation becomes much similar to that of the Sihwa project in Korea and that of the Isahaya project in Japan mentioned above, but its scale is too large and probably recorded as the largest single reclamation project in the world. It should be noted that the Saemangeum area is the last remaining estuary unclosed except for the Han River estuary in South Korea at present.

A serious influence by environmental changes has been detected in macrobenthic community during the period of the dike construction. The macrobenthic survey during the dike construction indicated that the species number and its density were decreased up to 45 and 214 ind./m^2 respectively in 1996. Particularly, the density of the dominant species found in 1996, *i.e*., *Laternula* cf. *limicola*, *Umbonium thomasi*, and *L. unguis* were further decreased in 2001 (Je *et al.* 2002). A comparison of the occurrence of *P. amurensis* before and after the launch of the dike construction may reflet some impact alteration. This species became dominant after the isolation of the Isahaya Bay in Ariake Sea, Japan by the dike construction, and survived in the bad aquatic condition for a long time (Sato 2002). It is noteworthy that the abundance of *P. amurensis* increased also in the Mangyung river estuary after the commencement of the dike embankment (Sato 2002).

One of the traditional fisheries on Korean tidal flats is the hand catch of clams such as *Tapes (Ruditapes) philippinarum, Mactra veneriformis, Meretrix petechialis,* and *Sinonovacula constricta.* Though few studies have been performed for the resource of those clams especially in the Saemangeum area, a great biomass of *S. constricta* was reported as ca 3 kg wet weight/m^2 in Namyang Bay and also in Saemangeum area (Koh 1997, Koh *et al.* 2002b). The daily catch amount by a fisherman is about 44 kg and amounted to about 44 US $ in a whole sale (Koh *et al.* 2002b). The clam fishery is still the major income and food source for inhabitants. However, the whole area of clam populations will be lost soon by the Saemangeum project.

Governmental Agency releases the simulated results on the water quality of the 'Lake Saemangeum' (a planned freshwater pond after completion of the dike construction) for 2012, because the project may not be proceeded by the law without saving the future water quality. However, ecological aspects of the Saemangeum area including benthic fauna and flora have seldom been assessed during the process of the dike construction. Strictly, the Korean central government has pursued the strategy for the reclamation project regardless of the unique ecological value of the native tidal flat, though there are still argument and conflict for stopping this project among the residents, citizens, scientists, governmental people and politicians.

5. CONCLUSION

Probably, we know only a small portion of the whole unique fauna and flora in the Asian tidal flats at present. The delay of the taxonomic study on benthic organisms, especially on some macrobenthic invertebrates and meiofauna, would be a serious problem. For example, more than 100 species of benthic diatoms, including many undescribed species, were found in only one spoon sample collected from the sediment surface of muddy tidal flat of the Isahaya Bay before closing by the dike (Otsuka 2000). These benthic diatoms are important to be the food of the *Boleophthalmus* mudskipper, and other macrobenthos etc. But studies on the benthic diatoms are very limited and/or delayed (*e.g*., Oh and Koh 1995).

Recent data suggested that the available habitats for the unique fauna and flora in the Asian tidal flats have been reduced enormously within recent 100 years by human impacts such as reclamation. Consequently, the native rich biodiversity may be seriously damaged with many species threatened to extinction before taxonomical description (namely, before we know their existence). Prompt further progress of the taxonomical studies should be desired in these areas.

Tidal flats in the Asian estuaries surely supply important foraging places for many migratory birds from autumn to spring, because these tidal flats are located along the East Asian-Australasian flyway. For example, a minimum of 2 million shorebirds use the tidal flats around the Yellow Sea during northward migration and about 40 % of those, approximately 1 million pass through the region on southward migration (Barter 2002). Particularly, the Saemangeum area is the most important places in South Korea during both northward and southward migration in terms of maximum counts as well as numbers of internationally important species supported.

The tidal flats have another important ecological function as foraging places for many fishes and as places supporting the fishery activity of a human being. The reduced species diversity in the tidal flats seems to cause the reduced variety of food supply for the migratory birds as well as fishes, leading to the collapse of the whole ecosystem and the crisis of traditional east-Asian human culture depending on the coastal activity of fisheries.

The several apparent changes of biological harmful effects in species diversity and native characteristics of their habitats on the Korean and Japanese tidal flats gave a warning message of huge crisis coming through by human impacts. It should be reminded that the whole areas of tidal flats along the coastline in Germany have been designated as the national conservation district with the legislation of National Park Law since 1985. The huge reclamation projects such as Sihwa and Saemangeum projects in Korea and Isahaya project in Japan should not be repeated, and particularly, an alternative and/or modification of the Saemangeum project should be made to return to the original ecosystem from the viewpoints of nature conservation for the long-term ecological values and sustainability of the Asian tidal flats.

6. ACKNOWLEDGEMENT

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7. REFERENCES

An, S.-M. and Koh, C.-H. 1992. Environments and distribution of benthic animals on the Mangyung-Dongjin tidal flat, west coast of Korea. *J. Korean Soc. Oceanogr.* 27: 78-90.

Azuma, M. 2000. Effects of the reclamation project in Isahaya Bay. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 320-337). Kaiyu-sha, Tokyo.

Azuma, M. 2001. What is the unusual change in Ariake Sea? *Iwanami Booklet* 539: 2-15.

Azuma, M. 2002. An unusual change of Ariake Bay and a hypothesis of the effect of the reclamation project in Isahaya Bay as its major cause. *Iden* 56: 80-85.

Barter, M. 2002. Shorebirds of the Yellow Sea; importance, threats and conservation status. *Wetlands International Global Series* 9: 1-103.

Choi, J.W. and Koh, C.-H. 1994. Macrobenthos community in Keum-Mankyung-Dongjin estuaries and its adjuscent coastal region, Korea. *J. Korean Soc. Oceanogr*. 29: 304-318.

Domoto, A. 2001. Why must the biodiversity be conserved? In M. Kawamichi, K. Iwatsuki and A. Domoto (Ed.), *Introduced alien invasive species: A menace to biodiversity* (pp. 1-13.). Tsukiji-shokan, Tokyo.

Harada, M. 1995. Minamata Disease: methylmercury poisoning in Japan caused by environmental pollution. *Crit. Rev. Toxicol*. 25: 1-24.

Henmi, Y., Azuma, M. and Yamaguchi, T. 2000. *Branchiostoma belcheri* in Ariake Sea. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 206-209). Kaiyu-sha, Tokyo.

Ishii, R. and Sekiguchi, H. 2002. Larval recruitment of the clam *Ruditapes philippinarum* in Ariake Sound, southern Japan. *Jap. J. Benthology* 57: 151-157.

Izuka, A. 1908. On the breeding habit and development of *Nereis japonica* n. sp. *Annot. Zool. Japon* 6: 295-305.

Je, J.-G., Shin, S.-H., Koo, B.-J. and Shin, H.-C. 2002. Changes in zoobenthos on the Saemangeum tidal flats during the dike construction. In D.-S. Cho *et al*. (Eds.), *Proceedings of VIII INTECOL International Congress of Ecology* (p. 97). Seoul.

Kawaguchi, O., Yamamoto, T. and Matsuda, O. 2002. Characteristics of water quality in Ariake Bay, Kumamoto, Japan, in FY2000-the year of the devastated Nori crop. *Oceanogr. Jap*. 11: 543-548.

Khim, J.S., Villeneuve, D.L., Kannan, K., Lee, K.-T., Snyder, K.T., Koh, C.-H. and Giesy, J.P. 1999. Alkylphenols, polycyclic aromatic hydrocarbons (PAHs), and organochlorines in sediment from Lake Shihwa, Korea: Instrumental and bioanalytical characterization. *Environ. Toxicol. Chem*. 18: 2424-2432.

Kikuchi, T. 2000. Conservation significance of estuarine tidal flats. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 306-317). Kaiyu-sha, Tokyo.

Koh, C.-H. 1997. Korean megatidal environments and tidal power projects: Korean tidal flats-biology, ecology and land uses by reclamation and other feasibilities. *La Houille Banche* 3: 66-78.

Koh, C.-H. and Shin, H.-C. 1988. Environmental characteristics and distribution of macrobenthos in a mud flat of the west coast of Korea (Yellow Sea). *Netherlands J. of Sea Res*. 22: 279-290

Koh, C.-H. 2001. Geomorphology and dyking of the Korean tidal flat, In C.-H. Koh (Ed.), *The Korean tidal flat: Environment, biology, and human* (pp. 76-85). Seoul National University Press, Seoul.

Koh, C.-H., Khim, J.S., Villeneuve, D.L., Kannan, K. and Giesy, J.P. 2002a. Analysis of trace organic contaminants in environmental samples from Onsan Bay, Korea. *Environ. Toxicol. Chem*., 21: 1796-1803.

Koh, C.-H., Hayashi, S. and Takeda, J. 2002b. The catch of *Sinonovacula constricta* in Saemangeum is compared with a gardening in Ariake Sea: a video film. In D.-S. Cho *et al*. (Eds.), *Proceedings of VIII INTECOL International Congress of Ecology* (p. 140). Seoul.

KORDI 1981. *Report on water quality monitoring in coastal areas of Banweol, Ulsan, Changwon, and Tochon*, 302 pp.

KORDI 1999. *A study on environmental changes in Shihwa lake*, 363 pp.

Kosuge, T. 2000. Crabs. In M. Sato (Ed.) *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 72-94). Kaiyu-sha, Tokyo.

Lee, Y.-H. and Koh, C.-H. 1994. Biogenic sedimentary structures on a Korean mud flat: spring-neap variations. *Netherlands J. Sea Res*. 32: 81-90

MOMAF 2001. *MOMAF-PEMSEA regional workshop on Sihwa, Management strategy and regional initiatives for coastal environmental management*. March 2001, Seoul. Korea, 318 pp.

Morse, E.S. 1879. Shell mounds of Omori. *Mem. Sci. Dep. Univ. Tokio, Jap*., 1: 1-36.

Nakahara, Y. and Nasu, H. 2002. Report from the coastal areas of Ariake Sound, Kumamoto Prefecture; the main fisheries ground for the clam *Ruditapes philippinarum* populations in Japan. *Jap. J. Benthology* 57: 139-133.

Oh, S.H. and Koh, C.-H. 1995. Distribution of diatoms in the surficial sediments of the Mangyung-Dongjin tidal flat, west coast of Korea (Eastern Yellow Sea). *Mar. Biolo*. 122: 487-496.

Onikura, N. 2000. Spawning site of *Trachidermus fasciatus*. In M. Sato (ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 224-225). Kaiyu-sha, Tokyo.

Otsuka, T. 2000. Diatoms on tidal flats in Isahaya Bay. In M. Sato (ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 69-71). Kaiyu-sha, Tokyo.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev*. 1978: 229-311.

Rural Development Corporation 2002 *Tideland reclamation in Korea*. 405 pp.

Ryu, J.S., Choi, J.W., Kang, S.G., Koh, C.-H. and Huh, S.H. 1997. Temporal and spatial changes in the species composition and abundance of benthic polychaetes after the construction of Shihwa dike (west coast of Korea). [The Sea] *J. Korean Soc. Oceonogr*. 2: 101-109.

Sato, M. 2000. Polychaetes. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 184-205). Kaiyu-sha, Tokyo.

Sato, M. and Takita, T. 2000. Fauna and general environments in Ariake Sea. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 10-35). Kaiyu-sha, Tokyo.

Sato, M., Azuma, M., Sato, S., Kato, N. and Ichikawa, T. 2001. What happen around Isahaya Bay in Ariake Bay? *Kagaku*, 71: 882-894.

Sato, M. and Nakashima, A. 2003. A review of Asian *Hediste* species complex (Nereididae, Polychaeta) with descriptions of two new species and a redescription of *Hediste japonica* (Izuka 1908). *Zool. J. Linnean Soc.* 137: 403-445.

Sato, S. 2000. Bivalves. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 150-183). Kaiyu-sha, Tokyo.

Sato, S. 2002. Faunal response of Bivalves and Gastropods to large environmental disturbances caused by the construction of dyke for reclamation. *Jap. J. Benthology*, 57: 106-118.

Shimoyama, S. 2000. Geological history of Ariake Sea and establishment of indigenous species. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 37-48). Kaiyu-sha, Tokyo.

Shin, H.-C., Choi, J.W. and Koh, C.-H. 1989. Faunal assemblages of benthic macrofauna in the inter- and subtidal region of the inner Kyunggi-Bay, west coast of Korea. *J. Korean Soc. Oceanogr.* 24: 184-193.

Sugano, T. 1981. *Ariake Sea*. Tokai University Press, Tokyo. 194 pp.

Takita, T. 2000. Fishes. In M. Sato (Ed.), *Life in Ariake Sea: Biodiversity in tidal flats and estuaries* (pp. 213-252). Kaiyu-sha, Tokyo.

Tamaki, A., Mahori, N., Ishibashi, T. and Fukuda, H. 2002. Invasion of two marine alien gastropods *Stenothyra* sp. and *Nassarius* (*Zeuxis*) *sinarus* (Caenogastropoda) into the Ariake Inland Sea, Kyushu, Japan. The Yuriagai: *J. Malacozool. Ass. Yamaguchi* 8: 63-81.

Tsutsumi, H., Okamura, E., Ogawa, M., Takahashi, T., Yamaguchi, H., Montani, S., Kohashi, N., Adachi, T. and Komatsu, T. 2003. Studies of the cross section of water in the innermost area of Ariake Bay with the recent occurrence of hypoxic water and red tide. *Oceanogr. Jap*. 12: 291-305.

Ui, J. 1992. Minamata Disease. In J. Ui (Ed.), *Industrial Pollution in Japan* (pp. 103-132). United Nations University Press, Tokyo.

Unoki, S. 2002a. Temporal change of tides and currents in Ariake Bay, related to the reclamation in Isahaya Bay. *Sea and sky*, 78: 19-30.

Unoki, S. 2002b. Essay on the environmental change in coastal waters caused by various human impacts originating in rivers, mainly from a physical viewpoint. *Oceanogr. Jap.* 11: 637-650.

Unoki, S. 2003a. Why did the tide and the tidal current decrease in Ariake Bay? *Oceanogr. Jap*. 12: 85-96.

Unoki, S. 2003b. The results of re-examining the recent decay of tide in Ariake Bay, based on smoothed data of observations. *Oceanogr. Jap*. 12: 307-313.

Wada, K., Kosuge, T. and Takayama, J. 1992. Distribution of *Ilyoplax pusilla* and *I. deschampsi* (Brachyura: Ocypodidae). *Res. Crustacea*, 21: 139-146.

Wu, B., Sun, H. and Li, Y. 1992. A sharp decrease in the number of animal species in Kiaochow Bay, Qingdao (Tsingtao), China. *Mar. Pollut. Bull.* 24: 216-217.

Yanagi, T. 2002. Structure of biological productivity of lower trophic levels in Ariake Sea: in relation to the problem of a poor catch of Nori. *Bull. Jap. Soc. Industr. Appl. Mathematics*, 12: 49-53.

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CHAPTER 10

CONSERVATION AND MANAGEMENT OF GRASSLAND BIODIVERSITY IN EAST ASIA

1. INTRODUCTION

East Asia has various types of grasslands, such as inland arid and semi-arid natural grasslands in China and Mongolia, and artificially managed semi-natural grasslands in wet monsoon areas like Japan. Diversified utilization and livestock farming are carried out on these grasslands. A variety of grasslands have been maintaining diversified organisms characteristic to grassland ecosystems. However, in those grasslands, irrespective of the types and areas, deterioration of the diversity of grassland organisms is going on. The causes of the decline in biodiversity differ, depending on the particular grassland in question. In the Chinese and Mongolian grasslands, overgrazing associated with retrogression and desertification due to increases in the human population and settlements has resulted in the decline and even extinction of some species of wildlife. In the wet monsoon areas, decreases in grassland area and insufficient management of grasslands due to the decline of livestock farming and the rural lifestyle have led to a deterioration of grassland biodiversity. Accordingly, there is an acute need for conservation and management of grassland biodiversity in these areas.

Different grasslands require different strategies for the conservation and management of their biodiversity. This paper summarizes the present conservation issues in the grasslands and presents future prospects for the conservation and management of the grasslands in East Asia.

2. GRASSLANDS IN EAST ASIA

The grasslands of East Asia are at the eastern fringes of the vast plain that stretches 8,000 km from Eastern Europe west to North-eastern China. Worldwide, there are about 40-50 million km^2 grasslands comprising about 40% of the total land area. The extent of the grassland area in Asia is estimated to be about 9 million km^2, and comprises about 17% of the world's grasslands (Table 1). The major two grassland-containing countries, China and Mongolia, account for the majority of this area.

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China has about 4 million km^2 of grasslands, and Mongolia has about 1.3 million km^2 of grassland area.

Table1. World Regions, Grassland Area (million km^2)

Asia	*Europe*	*Middle East* and *N. Africa*	*Sub-Saharan Africa*	*North America*	*C. America* and *the Caribbean*	*South America*	*Oceania*
8.89	6.96	2.87	14.46	6.58	1.05	4.87	6.86
16.6(%)	12.5(%)	5.4(%)	27.0(%)	12.3(%)	2.0(%)	9.1(%)	12.8(%)

Revision from White *et al.* (2000)

Table 2. Conversion (%) of Grassland Ecoregions

Ecoregions [a]	*Current Grassland* [b]	*Estimated Conversions:*		
		Cropland	*Urban*	*Other*
Asian/Daurian Steppe	71.7	19.9	1.5	6.9
North American Tallgrass Prairie	9.4	71.2	18.7	0.7
South American Cerrado Woodland and Savanna	21.0	71.0	5.0	3.0
Central and Eastern Mopane and Miombo Woodlands	73.3	19.1	0.4	7.2
Southwest Australian Shrublands and Woodlands	56.7	37.2	1.8	4.4

Revision from White *et al.* (2000)

[a] Ecoregions are defined as "relatively large unit of land containing a district assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change" (Olsen *et al.* 2001)

[b] Percentage of current grassland remaining.

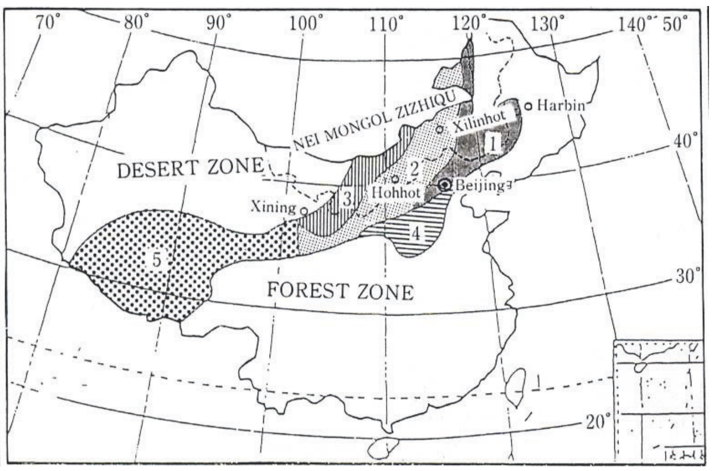
In general, grasslands are distributed in arid zones. The world has been divided into a set of six aridity zones on the basis of the ratio of the mean annual precipitation to the mean annual potential evapotranspiration (White *et al.* 2002). The approximate distribution of world grasslands corresponding to the drylands encompasses three zones, i.e., arid, semi-arid, and dry sub-humid zones (White *et al.* 2002).

Grasslands are maintained not only by particular climatic factors, but also by certain human-related influences, such as burning, harvesting, and livestock grazing. Accordingly, the grasslands are also distributed among humid zones where the forest is the climax community. However, one noticeable feature of the grasslands in East Asia is that there is a huge extension of open landscape. When the percentages of

grassland with each class of woody vegetation (>5 m mature vegetation) cover were compared throughout the world using Advanced Very High Resolution Radiometer (AVHRR) land cover classification data with 1-km spatial resolution, Asia has been found to possess the highest percentage of the cover class offering the least amount of (<10%) woody vegetation (White *et al.* 2000). Another noticeable feature of the grasslands in East Asia is that the grasslands have been intact over time. As regards the grasslands in other areas (e.g., North America or South America), 75-90% of the grassland area has been converted into croplands or into urban regions (Table 2).

3. GRASSLANDS AND THEIR BIODIVERSITY IN CHINA

3.1. Grasslands in China



Source: Shiyomi and Saito (1988); Zhu *et al*. (1985)
1. Meadow steppe; 2. Typical steppe; 3. Desert steppe; 4. Shrub steppe; 5. Alpine steppe

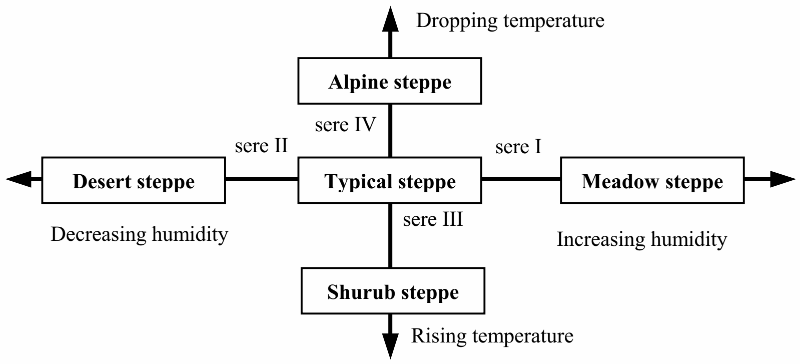
Figure 1. Distribution of grasslands in China.

China is the biggest grassland-containing country in Asia. The grasslands cover about 41% of the total land area and they are the largest biome in China. According to Zhu *et al*. (1985), grasslands in China can be categorized into two major types, namely, steppe and meadow. Steppe is an area of zonal vegetation dominated by perennial xeric herbs. These grasslands are affected by certain climatic factors such as temperature and humidity. The other type of grassland, meadow, is not a zonal type of vegetation dominated by mesic perennial herbs. These grasslands are distributed throughout various climatic zones.

Figure 1 shows the distribution map of five major Steppe grasslands in China. The five types of steppe in China are Meadow steppe, Typical steppe, Desert steppe,

Shrub steppe, and Alpine steppe. These grasslands are distributed along dryland belts. Figure 2 shows a schema representing the relationship among the five types of steppe in a series of temperature and humidity clines. In the center of the Figure, a Typical steppe is represented, indicating a geographical center in the steppe belt.

At points where the humidity increases, Meadow steppe appears. In contrast, where the humidity decreases, Desert steppe appears. In addition, where the temperature decreases, such as at high altitudes, Alpine steppe is found. On the other hand, where the temperature becomes high, Shrub steppe is seen.



Source: Zhu *et al.* (1985)

Figure 2. Ecological series of stepe types in China.

Meadow accounts for about one-fifth of the Chinese natural grasslands. The meadows can be classified into three major types. Typical meadows are dominated by mesic broad-leaf forbs, which occur mainly at the forest edges or in open areas in a mixed deciduous and summergreen deciduous forest. Such vegetation is usually a secondary type of growth that follows artificial deforestation. Marsh meadows are developed at imperfectly drained, low-lying habitats, and they consist primarily of hygrophilous herbs, predominantly *Carex* plants. Salt meadows consist of mesic salt-tolerant herbs. Such herbs are widely scattered over the saline-alkali flood plains around lakes in the grassland and desert zones.

3.2. Biodiversity of grasslands in China

China has diverse grassland species, i.e., more than 30,000 species of higher plants have been identified throughout the country. About 7,000 of these plants are grassland species (Biodiversity Committee of the Chinese Academy of Sciences 1992). In Inner Mongolia, where the majority of the steppe grasslands is distributed, 8 species of amphibians, 21 reptiles, 376 birds, and 118 mammals have been recorded (Fen *et al.* 1995). These species accounted for 3 to 30% of the total species found in China. According to Li and Yang (1995), 135 rangeland plant species were

classified as rare and endangered species. Typical grassland birds, such as the steppe eagle (*Aquila nipalensis*) and the great bustard (*Otis tarda*), have been listed in the Convention of International Trade in Endangered Species (CITES) Appendix II and in the Red Data Book of China. Some grassland mammals, such as the wolf (*Canis lupus*; CITES Appendix II) and the Mongolian gazelle (*Procapra gutturosa*; Grade II of the State Protected Wildlife in China) are also listed in the Red Data Book.

In recent decades, the biodiversity of grasslands in China has been threatened by several factors, including desertification, agriculture, collection of medicinal herbs, mining, construction of roads, invasion of exotic species, and grazing (Fan *et al.* 2002). It has been estimated that approximately 100 million hectares of rangelands have been seriously degraded due to the desertification caused by wind erosion and sand drifts. Agriculture has also led to some serious problems. For example, 19.3 million hectares of grasslands have been ploughed for croplands since 1949. In addition, 18.2% of the croplands in China are derived from ploughed grassland.

Massive quantities of native vegetation in the grasslands were removed and replaced by crops. During this process, the soil was exposed and became vulnerable to wind and water erosion. Another problem has been the overexploitation of biological resources. Due to excessive collection of medicinal herbs and the poaching of rare species, many medicinal grassland species, such as *Scutellaria baicalensis* and *Glycyrrhiza uralensis*, are now at high risk of extinction. In addition, it is estimated that 9% of the desertification of land has been related to mining, oil drilling, and the construction of roads in the northern grasslands in China. The effects of exotic species on the diversity of the grassland ecosystem have also become increasingly serious in China (Fan *et al.* 2002).

However, it should be noted that the largest problem in this context has been overgrazing. Due to long-term overgrazing, more than half of the grasslands have undergone degradation in China. Particularly, one quarter of this area has been seriously degraded. Wuyunna *et al*. (1999) reported that the plant species composition varied depending on the various grazing pressures in the Xilingol district, central Inner Mongolia. For instance, the biomass of *Leyumus chinensis,* a dominant species of that grassland, was lower at sites of overgrazing than at light-grazing sites. In Hulunber, northern Inner Mongolia, several alien grazing-tolerant weeds such as *Potentilla bifurca*, *Plantago depressa*, and *Chenopodium album* have replaced the native species near villages where the grazing pressure was most concentrated (Shi *et al.* 1998).

Soil hardening occurred around villages associated with overgrazing. Furthermore, Shi *et al*. (2001) showed that species richness, vegetation height, and vegetation coverage decreased as soil hardness increased (Table 3). In addition, grazing allowed unpalatable plant species such as *Iris dichotoma* to proliferate. Some other species also increased by association with *I. dichotoma,* leading to a change in the plant communities in this region (Takatsuki and Jiang 1999). Furthermore, species richness and the abundance of grassland birds also decreased with changes in vegetation conditions following increasing grazing pressure in the grasslands of this region (Shi *et al.* 2001) (Table 4).

Table 3. Correlation coefficients (r) for the relationship among soil hardness, vegetation height, vegetation coverage, and species richness of plant at 15 sites in Xinbarhuyouqi, Hulunber grassland, northern Inner Mongolia

	Soil hardness (kg/cm^2)	*Vegetation height (cm)*	*Vegetation coverage (%)*
Vegetation height (cm)	- 0.69**		
Vegetation coverage (%)	- 0.72**	0.72**	
Species richness of plants	- 0.72**	0.84***	0.72**

**p<0.01, *** p<0.001 Source: Shi *et al.* (2001)

Table4. Correlation between the diversity and abundance of birds and the soil and vegetation parameters at 15 sites in Xinbarhuyouqi, western Hulunber grassland, northern Inner Mongolia

	Correlation coefficients (r)		
	Soil hardness (kg/cm^2)	*Vegetation height (cm)*	*Vegetation coverage (%)*
Species richness of birds	n.s.	0.72**	0.83***
Abundance of birds	- 0.72**	0.91***	0.81***

n=15; ** p<0.01, *** p<0.001 Source: Shi *et al.* (2001)

Remarkable population increases, both in livestock and human beings, in recent decades have been responsible for the decrease in the grassland biodiversity of these regions. Sociological changes facilitated the shift in the grazing system from that of nomadism to settlement in the grasslands (Shi and Maruyama, in press). Such change has resulted in the marked and rapid retrogression of grassland biomes around settled villages.

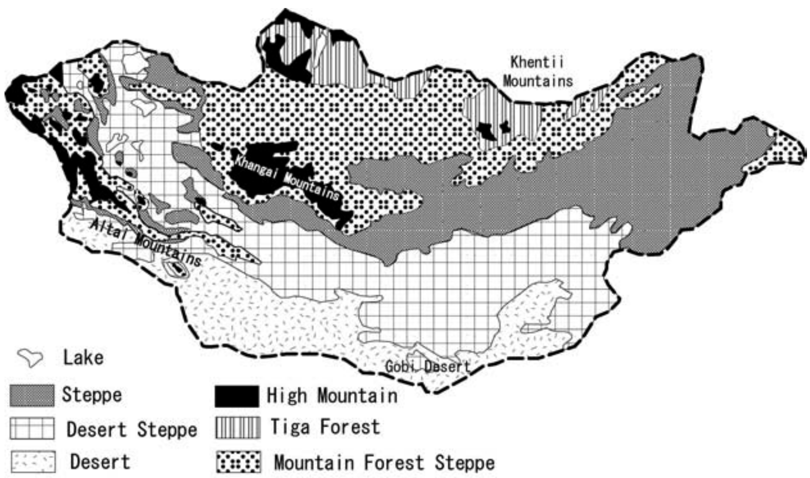
Thus, the following points must be considered to conserve the grassland ecosystem and to allow for the coexistence of the natural environment and the people living in these regions in Inner Mongolia: 1) the regulation of increases in the populations of both livestock and humans; 2) the establishment of natural reserves and the introduction of ecotourism and green tourism into buffer zones that would effectively separate and limit the territories of local people and wildlife; 3) the use of a variety of livestock farming systems and the development of strategies other than

grazing near and in towns; 4) the promotion of environmental education for people living in the regions (Shi and Maruyama, unpublished).

4. GRASSLANDS AND THEIR BIODIVERSITY IN MONGOLIA

4.1. Grasslands in Mongolia

Mongolia contains vast grasslands that cover 117 million hectares, which accounts for about 75% of the national territory. Mongolia is divided into six natural zones that differ in terms of climate, landscape, soil, flora, and fauna (Myagmarsuren and Tumurbaatar 2000). These six natural zones are as follows: High mountain, Taiga forest, Mountain forest steppe, Steppe, Desert steppe, and Desert. Of these, the Mountain forest steppe, the Steppe, and the Desert steppe are generally grassland landscaps (Figure 3).



Revision from Myagmarsuren and Tumurbaatar (2000)

Figure 3. Distribution of grasslands in Mongolia.

The Mountain forest steppe zone occurs at the lower elevations of the Khangai and Khentii mountainous regions. In the cooler and moister northern slopes, mixed coniferous forest is found. On the other hand, the southern slopes are covered with steppe plants. These areas occupy 27% of the territories of Mongolia. The Desert steppe zone includes a depression of Great Lakes, a valley of lakes, and the Middle and Eastern Gobi areas.

These areas cover 20% of Mongolia's total area. The Steppe zone covers the eastern and central parts of the country. The so-called "sea of grass" landscape, i.e., gently rolling terrain and extremely flat areas, covers 23% of the total land area. This type of grassland ecosystem provides a good habitat for thousands of Mongolian gazelle, as well as for a diverse array of migratory birds.

4.2. Biodiversity of Grasslands in Mongolia

Mongolia's diverse and distinctive vegetation includes an important portion of the Asian plant communities. In the case of the flora, more than 3,000 species of vascular plants, 927 lichens, 437 mosses, 875 fungi, and numerous algae have been recorded (Finch 1996). Over 100 plant species are listed in the Mongolian Red Book as rare or endangered. Mongolia's fauna represents a mixture of species from the northern taiga of Siberia, the steppe, and the desert of Central Asia. The fauna include 136 species of mammals, 436 birds, 8 amphibians, 22 reptiles, 75 fish, and numerous invertebrates (Finch 1996).

In contrast to the neighbouring countries such as Russia and China, Mongolia's grasslands are in good condition (Sneath 1998). However, fire patterns, overgrazing, climate change, mining, vehicular traffic on the steppe, and other pressures threaten grassland biodiversity in Mongolia as well (Ariungerel 2000). In particular, overgrazing remains the most serious reason for the degradation of grasslands. The traditional nomadic movement for raising livestock has been replaced by more sedentary methods. The highest levels of degradation have been found where livestock mobility was most restricted. Under these pressures, the diversity of plant species in areas near town centers has decreased as much as 80% (Finch 1996). The percentage of degraded grassland in Mongolia has been estimated as ranging from 4% to 33% (World Resources Institute 2000).

Some conservation programs for grasslands in Mongolia have recently progressed. The Durian steppe, located at the border of the three countries including Russia and China, was selected as one of the World Wildlife Fund (WWF)'s Global 200 Ecoregions, due to its high conservation value (Olson and Dinerstein 1998). Selection of Ecoregions is the first attempt to achieve representation of all major habitat types on a global scale. The primary objective is to promote the conservation of distinctive ecosystems harboring globally important biodiversity and ecological processes (Olson and Dinerstein 1998). Within Eastern Mongolia, three large "strictly protected areas" have been established in 1992 (*e.g.* Mongol Dornod, Nomrog, and Mongol Daguur) (Chimed-Ochir 2000). The total area under protection amounts to approximately 10,000 km^2, which corresponds to 8% of the Dornod Aimag territory.

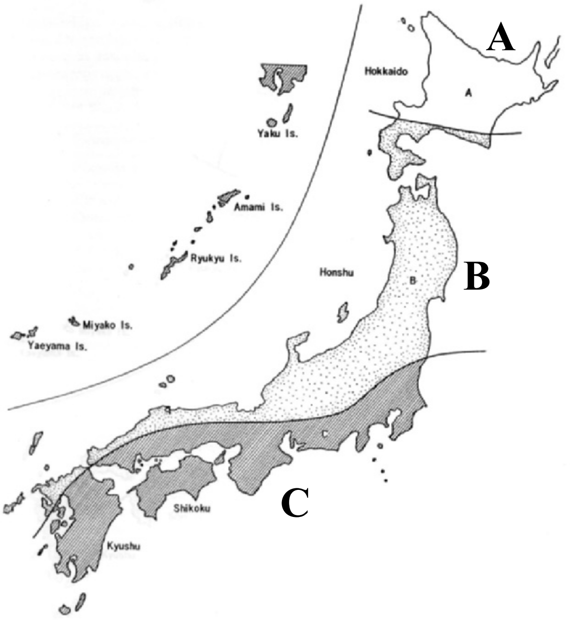
5. GRASSLANDS AND THEIR BIODIVERSITY IN JAPAN

5.1. Grasslands in Japan

Japan is a slender country extending from north to south. The four climatic zones of Japan are subarctic, cool temperate, warm temperate, and subtropical. The annual precipitation lies in the range of 1,000 to 3,500 mm. Due to this large amount of precipitation, forest is the climax community. Although invasion of tree species into the grasslands could be delayed as a result of predation by herbivorous mammals (e.g., the Japanese field vole *Microtus montebelli* (Shimoda 2001) or the sika deer *Cervus nippon* (Takatsuki 1989, Takatsuki and Gorai 1994)), their impact on maintaining the grasslands are currently thought to be limited in Japan. In general, most grasslands in Japan have been maintained by human-related influences, such as harvesting, burning, and livestock grazing.

The Japanese grasslands have been classified into six major types, depending on three climatic zones and two human-related influences (Numata 1969, Figure 4). In zone A, the climatic zone is a subarctic or cold-temperate zone. Where the grazing is conducted in this zone, *Poa pratensies* becomes dominant in the grassland. On the other hand, where mowing occurs, *Sasa* bamboo becomes dominant. In zone B, *Zoisia japonica* becomes dominant under conditions of grazing, while *Miscanthus sinensis* becomes a dominant species with mowing. In zone C*, M. sinensis* and *Pleioblastus species*, another type of bamboo, occur together under conditions of mowing, while the mixture of *Z. japonica* and *Pleioblastus* species become dominant with grazing. According to an advance in vegetation study in the southern islands of Japan, the subtropical zone has been added to this classification (Nishimura *et al.* 2001a). The relationship between these grassland vegetation zones and climatic factors were examined, and the border of each zone was revised in recent studies (Nisimura *et al.* 2001b, Urano *et al.* 2001)

At the present time, the grasslands of Japan occupy only 3% of the total territory (Shoji 2003). The distribution is clustered in the Northern Hokkaido and central Kyushu regions. Just 80 years ago, however, the extent of the grasslands ranged over 3 million hectares (Iwanami 1995), and grasslands occupied about 11% of the total territory (Himiyama *et al.* 1991). In those days, grasslands were maintained by the gathering of useful resources such as manure, fuel, building materials, and fodder (Takahashi and Nakakoshi 1999, Takeuchi *et al.* 2001). However, due to drastic economic and sociological changes in the rural community, the area that had been useful for a more traditional lifestyle has been abandoned.



Revision from Numata (1969)

Figure 4. The grassland zones in Japan.

According to a national-scale analysis of a topological map database conducted by Yamamoto (2001), two major patterns of change in the landscape were associated with the decrease in grassland area after World War II. One of these patterns is characterized by the continuous reduction of the grassland area located primarily in the mountainous areas of eastern Japan. In this pattern, the meadow and pasture grasslands, located in easily accessible areas near settlements, were changed into planted coniferous forests. The other pattern of change that has been widely observed in the mountainous area of western Japan is characterized by an irreversible shift from grasslands to coniferous forests. In this pattern, the grasslands were usually located far from residential areas to avoid the risk of fire due to the burning of the grasslands. After the decline in the need for fuel and manure among farmers, the grasslands were abandoned and were changed into either secondary deciduous forests or some coniferous forests composed of such as, *Pinus densiflora* for the progress in succession.

5.2. Conservation of grasslands in Japan

With the rapid reduction in areas of grassland, many grassland species have become endangered. In the oldest anthology of waka poems, "Manyoushyu",

published in 759, referred to 7 grassland species that bloomed in autumn. Among these most familiar grassland species, two were listed in the Red Data Book in Japan (Ministry of Environment 1997). In the comparative analysis of three local red lists of plants, 13-15% of the highly endangered species originally grew in grassland habitats (Fuji 1999). This figure is higher than the average given in each local red list. This high risk of grassland species extinction is thought to be caused by the development of hilly areas and by an increase in abandoned cultivated lands in hilly and mountainous areas.

Animals associated with grasslands are also threatened. Among 236 butterfly species occurring in Japan, 62 species (26.3% of the total) are listed in the Red Data Book (RDB) (Ministry of Environment 2000); 10, 20, and 32 species are listed under the categories of Endangered, Vulnerable, and Near Threatened (IUCN Red List categories), respectively (*Table 5*). Of 62 RDB species, 39 (62.9% of RDB species) are grassland species. In the Endangered, Vulnerable, and Near Threatened species, 80, 65.0, and 56.3% of the species are grassland species, respectively. Thus, the higher the extinction risk, the higher the ratio of grassland species, indicating that grassland butterflies are more threatened than other types of butterfly. *Pyrgus maculatus* (Hesperiidae), *Shijimiaeoides divinus* (Lycaenidae), and *Fabriciana nerippe* (Nymphalidae) are highly endangered grassland butterflies.

Conversions of grasslands for other uses, abandonment and insufficient management of pastures and meadows, as well as the improvement of semi-natural grasslands into sown grasslands, are all responsible for the reduction in the butterfly populations (Imura 2001).

Table 5. Butterfly species listed in the Red Data Book and grassland species in each category

*Category**	*Number of species / %*			
	All species	*% of the total number*	*Grassland species*	*% to RDB species*
Total number of species**	236			
RDB species***	62	26.3	39	62.9
Extinct	0	0.0	0	0.0
Endangered	10	4.2	8	80.0§
Vulnerable	20	8.5	13	65.0§
Near Threatened	32	13.6	18	56.3§

* based on IUCN categories.
** Total number of butterfly species occurring in Japan.
*** Butterfly species listed in the Red Data Book (Ministry of Environment 2000).
§ The ratio of the grassland species in the category is significantly larger than that of the non-grassland species (G<0.01).

A traditional burning management of the grassland conserves *Shijimiaeoides divinus* by increasing not only the host plant but also nectar plants and ant species attending upon the butterfly larvae (Murata *et al.* 1998). Typical grassland birds, such as *Locustella pryeri, Circus spilonotus, Emberiza yessoensis, Emberiza aureola,*

Gallinago hardwickii, and *Cotrnix japonica,* are also listed in the Red Data Book (Ministry of Environment 2002). Shoji (2003) predicted using GIS data that in each region in Japan, higher coverage of semi-natural grasslands than presently exists would increase the species richness of butterflies and birds.

To conserve grassland species and their diversity in Japan, two major approaches are of potential benefit. One would be the promotion of sustainable agriculture, which would include activities such as grazing, harvesting, and burning. A large extent of grassland cannot be maintained without such activities. Recently, these traditional agricultural activities have been supported by nonprofit organizations (NPOs) organized for the conservation of semi-natural grasslands. In the Aso area, where the largest semi-natural grassland in Japan has been maintained for over a thousand years, the Aso Green Stock Foundation was established in 1995 for the promotion of local livestock farming, educational campaigns, research and study activities, conservation of water resources and natural landscape, and green tourism (Yamauchi and Takahashi, 2002). In Mt. Sanbe, in the southern part of Japan, another NPO was established in 1992 for the restoration and expansion of grazing and burning activities (Naito and Takahashi, 2002).

Another approach would be the establishment of a natural reserve for grassland species. This would be a suitable approach to support endangered species, but it would be very expensive in terms of both cost and labor required to control the degree of disturbance. Therefore, with this approach, the area of application cannot be very large. In the Koshimizu National Reserve, periodic burning has been tentatively conducted for the restoration of grassland vegetation that is characteristic of the coastal dunes (Tsuda *et al.* 2002). The effect of removing competitive species such as *Sasa senanensis* was examined in the Togakushi Plateau, for the conservation of a wildflower habitat (Ohkubo and Maekawa 1993).

6. CONCLUSION

The biodiversity of grasslands is either decreasing or threatened throughout East Asia. Therefore, conservation strategies are urgently needed in these countries. To establish a systematic conservation plan, the following six stages should be considered (Margules and Pressey 2000). First, during the planning process, clear choices need to be made about the features to be used as surrogates to achieve overall biodiversity in grasslands. The Red Data Book of each country should be a primary data source for listing “hot spot” areas for conservation. Second, such a plan must be based on explicit goals, preferably translated into quantitative, operational targets. The reasons for the reduction of grassland biodiversity differ among regions. However, the major causes for this reduction can be categorised as either overuse of the grasslands, seen in arid climate zones, and underutilization of the grasslands in humid climate zones. In both cases, the problems of overuse and underutilization result from neglecting to use the grasslands in a sustainable manner.

The sustainable use of grasslands should be regarded as a common goal for conserving biodiversity, beyond regionality, although the means of reaching this

goal will differ among regions. Third, such a plan would identify the extent to which conservation goals have been met by existing conservation plans. Currently, many action plans have been carried out in Japan, Mongolia, and China. The present plans for conservation should be reviewed, and their limitations be considered. Fourth, a simple, explicit method for establishing and designing new conservation strategies must be devised to complement existing plans for achieving goals. Fifth, a plan must employ explicit criteria for implementing conservation strategies, especially with respect to the scheduling of protective management in cases in which not all candidate plans can be conducted at once. Finally, such a plan would adopt explicit objectives and mechanisms for maintaining the required value of conserved grassland such as persistence of high-biodiversity. Adaptive modification of objectives would be required after monitoring the effect of conservation activities.

The socio-economic aspects of biodiversity issues are also necessary to consider to solve these conservation problems. In arid zones like Inner Mongolia of China, and Mongolia, the regional economy depends too much on the grasslands. Establishment of economic activities other than grazing (*e.g.*, ecotourism and green tourism, and food, fur and leather industries) will allow to shift cases of overuse to sustainable use of the grasslands. Conversely, in humid zones, grazing is not profitable enough to sustain livestock farmers, leading them to quit and shift to more profitable barn-feeding system. Thus, decreased dependence of the farmers on the grasslands results in the insufficient management of the grasslands. Shoji *et al.* (1999) evaluated the monetary value of a semi-natural grassland on Mt. Sanbe as 40 billion yens per year, using the contingent valuation method (CVM).

The Japanese government introduced a program of "direct payments in hilly and mountainous areas" from 2000 to compensate for the farmers' income for the preservation of farmlands (including grasslands) that have multi-functional roles such as preservation of national land, fostering water resources, and conservation of the natural environment (including issues of landscape and biodiversity; (Ministry of Agriculture, Forestry and Fisheries, Japan 1999)). Direct payment resulting from specific conservation activity should be a future option for conserving biodiversity in this area (Ferrero and Kiss 2002).

Thus, different grasslands will require different strategies for conserving biodiversity, depending on their geographical, climatic, and sociological conditions. However, it is important to acknowledge and communicate the importance of healthy grassland ecosystems in each country of East Asia, beyond their local differences. We must also promote transboundary partnerships among various specialists such as researchers, policy makers, and land managers beyond those coming from various countries in East Asia.

7. REFERENCES

Ariungerel, D. 2000. Rangeland monitoring in the Eastern Steppe Biodiversity Project (ESBP). *Seminar on the protection and conservation of grasslands in East Asia. August 14, 2000 Ulaanbaatar, Mongolia Proceedings*, 23-26. Retrieved April 14, 2002, from http://www.iucn.org/themes/wcpa/pubs/pdfs/Grassland8_00Proc.pdf

Biodiversity Committee of the Chinese Academy of Sciences. 1992. *Biodiversity in China Status and Conservation Needs.*Science Press, Beijing.

Chimed-Ochir, B. 2000. Priorities for the conservation and protection of the Durian Steppe in Mongolia. *Seminar on the protection and conservation of grasslands in East Asia. August 14, 2000 Ulaanbaatar, Mongolia Proceedings*, 50-53. Retrieved April 14, 2002, from
http://www.iucn.org/themes/wcpa/pubs/pdfs/Grassland8_00Proc.pdf

Fan, J.W., Chen, L.B., Zhong, H.P. and Liang, B. 2002. The vegetation diversity and its management of Chinese grassland ecosystem. In J.W. Fan and L.B. Chen (Eds.), *Grassland Ecosystem and its Management* (pp.38-55). Chinese Agricultural Science and Technology Press, Beijing.

Feng, L., Zhao, T. and Bi, J. 1995. Diversity of the wild animals of Inner Mongolia. In B. Li. (Ed.), *Research on Conservation of grassland biodiversity* (pp. 34-54). Inner Mongolia University Press, Huhehaote.

Ferrero, P.J. and Kiss, A. 2002. Direct payments to conserve biodiversity. *Science, 298*: 1718-1719.

Finch, C. 1996. *Mongolia's Wild Heritage-biological diversity, protected aras, and conservation in the land of Chingis Khan.* Retrieved April 14, 2002, from
http://www.un-mongolia.mn/archives/wildher/contents.htm

Fujii, S. 1999. A comparative analysis of habitat types of locally endangered plants in Japan. *The Japanese Journal of Conservation Ecology,* 4: 57-69.

Himiyama, Y., Iwagami, M. and Inoue, E. 1991. Reconstruction of land use of Japan circa 1900-1920. *Reports of the Taisetsuzan Institute of Science* 26: 55-63.

Imura, O. 2001. Agriculture and biodivesity. *Agriculture and Horticulture* 76: 1151-1157.

Iwanami, Y. 1995. Present status and problems of grasslands in Japan. *National parks* 534: 2-5.

Li, B. and Yang, C. 1995. The study of rangeland biodiversity conservation techniques in China. In B. Li (Ed.), *Research on Conservation of grassland biodiversity* (pp.15-20). Inner Mongolia University Press, Huhehaote.

Margules, C.R. and Pressey, R.L. 2000. Systematic conservation planning. *Nature* 405: 243-253.

Ministry of Agriculture, Forestry and Fisheries, Japan. 1999. *Annual Report on Food, Agriculture and Rural Areas in Japan FY 1999 (Summary)(Provisional Traslation).* Retrieved April 14, 2002, from
http://www.maff.go.jp/hakusyo/kaigai/ehakusyo99.htm

Ministry of Environment. 1997. *Red List of Threatened Plants of Japan.* Retrieved April 14, 2002, from
http://www.biodic.go.jp/english/rdb/red_plants.csv

Ministry of Environment. 2000. *Red List of Threatened Insects of Japan.* Retrieved April 14, 2002, from
http://www.biodic.go.jp/rdb/redlist/redlist.do05.csv

Ministry of Environment. 2002. *The Threatened Wildlife of Japan – Ave*s. (2nd ed.). Tokyo: Nature Environment Research Centre.

Murata, K., Nohara, K. and Abe, M. 1998. Effect of routine fire-burning of the habitat on the emergence of the butterfly, *Shijimiaeoides divinus asonis* (Matsumura). *Jpn. J. Ent.* 1: 21-33.

Myagmarsuren, D. and Tumurbaatar, E. 2000. The status of protected areas in the steppes of Mongolia. *Seminar on the protection and conservation of grasslands in East Asia. August 14, 2000 Ulaanbaatar, Mongolia Proceedings*, 15-22. Retrieved April 14, 2002, from
http://www.iucn.org/themes/wcpa/pubs/pdfs/Grassland8_00Proc.pdf

Naito, K. and Takahashi, Y. 2002. Conserving biological diversity on Semi-natural grassland in Mt. Sanbe. *Grassland Science* 48: 277-282.

Nishimura, N., Sasaki, H. and Nishimura, Y. 2001a. Ecological consideration for the distribution of natural grassland vegetation zones in relation to the climate and climate change in Japan. 1. Natural grassland vegetation types for the grassland zoning in relation to the climate in Japan. *Grassland Science,* 47: 82-85.

Nishimura, N., Sasaki, H. and Nishimura, Y. 2001b. Ecological consideration for the distribution of natural grassland vegetation zones in Relation to the climate and climate change in Japan. 2. The natural grassland vegetation types in relation to the climatic factors. *Grassland Science* 47: 86-92.

Numata, M. 1969. Progressive and retrogressive gradient of grassland vegetation measured by degree of succession-ecological judgement of grassland condition and trend IV. *Vegetatio* 19: 96-127.

Ohkubo, K. and Maekawa, H. 1993. The study on vegetation management by mowing on the *Sasa senanensis* dominant communities for the purpose of wildflower-habitat conservation. *Journal of the Japanese Institute of Landscape Architecture* 56: 109-114.

Olsen, D.M. and Dinerstein, E. 1998. *The GLOBAL 200: A representation approach to conserving the earth's distinctive ecoregions.* Retrieved from April 3, 2002, from WWF-US: http://www.worldwildlife.org/news/pubs/g200pdf.pdf

Olsen, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'amico, J.A., Itoua, I., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Ricketts, T.H., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P. and Kassem, K.R. 2001. Terrestrial ecoregions of the world: A new map of life on earth. *BioScience* 51: 933-938.

Shi, K., Maruyama, N., Gao, Z., Koganezawa, M. and Jiang, J. C. 1998. Impacts of settled grazing on the grassland ecosystem in the Nantun Area, northern Inner Mongolia. *Biosphere Conservation* 1: 73-80.

Shi, K., Maruyama, N., Gao, Z., and Koganezawa, M. 2001. Effects of livestock grazing on the bird communities in Xinbarhuyouqi, western Hulunber grassland, northern Inner Mongolia. *Biosphere Conservation* 4: 23-36.

Shi, K. and Maruyama N. Changes in livestock grazing system in the Hulunber grassland, northern Inner Mongolia. *Biosphere Conservation* (in press)

Shimoda, K. 2001. Succession of a *Miscanthus sinensis* grassland in Kirigamine. Results of the study for eight years. *Grassland Science* 47: 443-447.

Shiyomi, M. and Saito, Y. 1988. Visiing grasslands in the north China. *Grassland Science* 33: 418-427.

Shoji, A. 2003. Landscape ecological studies for semi-natural grassland conservation. *Grassland Science* 48: 557-563.

Shoji, A., Suyama, T. and Sasaki, H. 1999. Valuing economic benefits of semi-natural grassland landscape by contingent valuation method. *Grassland Science* 45: 88-91.

Sneath, D. 1998. State policy and pasture degradation in Inner Asia. *Science* 281: 1147-1148.

Takahashi, Y. and Nakagoshi, N. 1999. Man-made Japanese grasslands. *Iden* 53: 16-20.

Takatsuki, S. 1989. Effects of deer on plants and plant communities. *Japanese Journal of Ecology* 39: 67-80.

Takatsuki, S. and Gorai, T. 1994. Effects of sika deer on the regeneration of a *Fagus crenata* forest on Kinkazan Island, northern Japan. *Ecological Research* 9: 115-120.

Takatsuki, S., and Jiang, Z. 1999. Grazing effects on grassland community and a plant defence guild in Hulunbeier, northern China. *Biosphere Conservation* 2: 59-64.

Takeuchi, K., Washitani, I. and Tsunekawa, A. 2001. SATOYAMA: *The traditional rural landscape of Japan.* University of Tokyo Press, Tokyo.

Tsuda, S., Fujita, H., Ajima, M., Nishisaka, K. and Tsuji, T. 2002. Conservation and management of grassland vegetation on costal sand dune in the Koshimizu National Reserve, Hokkaido, Japan. *Grassland Science* 48: 283-289.

Urano, Y., Nishimura, N., Komoriya, Y. and Sasaki, H. 2001. Ecological consideration for the distribution of natural grassland vegetation zones in Relation to the climate and climate change in Japan. 3. The distribution of the indicate-species communities dividing the natural grassland vegetation zones according to the vegetation survey files of national survey on the natural environment. *Grassland Science* 47: 93-101.

White, R. P., Murray, S. and Rohweder, M. (2000). *Pilot analysis of global ecosystems grassland ecosystems.* Washington, DC: World Resources Institute. Retrieved April 14, 2002, from http://forests.wri.org/pubs_pdf.cfm?PubID=3057

White, R., Tunstall, D. and Henninger, N. 2002. An ecosystem approach to drylands: building support for new development policies. *Wourld Resaouces Institute Information Policy Brief, 1*, 1-14. Retrieved April 14, 2002, from http://pdf.wri.org/drylands_ecosystem_approach.pdf

World Resources Institute. 2000. *World resources 2000-2001: People and ecosystems: The fraying web of life.* Elsevier Science, Oxford.

Wuyunna, Nakamura, T. and Hayashi, I. 1999. Species diversity and phytomass of grasslands in Inner Mongolia, China. *Grassland Science* 45: 140-148.

Yamamoto, S. 2001. Studies on the effect of changes in rural landscape structure on secondary forest plants in Japanese rural areas. *Bulletin of the National Institute of Agro-Environmental Sciences* 20: 1-105.

Yamauchi, Y. and Takahashi, Y. 2002. Citizen's participation in conservation activities of Aso grassland. *Grassland Science* 48: 290-298.

Zhu, T., Li, J. and Zu, Y. 1985. Grassland resources and future development of grassland farming in temperate China. *Proceeding of the XV IGC, Kyoto, Jpan*, 33-38. The Japanese Society of Grassland Science, Tochigi.

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CHAPTER 11

SPREAD OF AN INTRODUCED TREE PEST ORGANISM - THE PINEWOOD NEMATODE

1. INTRODUCTION

Invasions of exotic species sometimes cause devastating effects in ecosystems they have invaded. Nowadays worldwide economic activity increases the flow of people and trading materials within and between continents, resulting in increasing occurrence of invasion of exotic species. The invasion process generally involves four phases: arrival, establishment in the new habitat, range expansion, and saturation (Liebhold *et al.* 1995). The spread pattern of invading organisms has been studied empirically and theoretically by many authors (Andow *et al.* 1990, Shigesada *et al.* 1995, Veit and Lewis 1996, Yamamoto *et al.* 2000).

Pinewood nematode, *Bursaphelenchus xylophilus* (Steiner et Buhrer) Nickle, is the causative agent of pine wilt disease (Kiyohara and Tokushige 1971). The infection of the nematode induces a rapid tree mortality of susceptible pine species such as *Pinus densiflora*, *P. thunbergii*, and *P. sylvestris* (Kiyohara and Tokushige 1971, Kondo *et al.* 1982). The nematode is inferred to be native to North America and introduced into Japan at the beginning of 20th century (Mamiya 1988). Since then it has spread to Korea, Taiwan, and China and devastated pine forests in East Asia. In Japan, for example, the annual loss of pines reached a maximum value of 2,430,000 m^3 in 1979 (Mamiya 1988), and then was held at a level of about 1,000,000 m^3 in the early half of 1990's. It was also found in Portugal in 1999 (Mota *et al.* 1999). The objective of this article was to determine the spread pattern of pinewood nematode at within-stand, local, and regional levels in Japan. For this purpose, we summarized the biology of the nematode and its vectors first.

2. BIOLOGY OF PINEWOOD NEMATODE

Infection of the nematode occurs through the feeding and oviposition wounds made by insect vectors (Mamiya and Enda 1972, Morimoto and Iwasaki 1972, Wingfield and Blanchette 1983). The nematodes enter the resin canals in the cortex and wood of tree, and move within feeding on epithelium cells of the resin canal at the early stage of infection (Mamiya and Kiyohara 1972, Ichihara *et al.* 2000). The nematode

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infection causes loss of hydraulic conductivity of xylem, which is closely related to the embolism of tracheids (Ikeda and Kiyohara 1995, Ikeda and Suzaki 1984). The embolism results from cavitation in the water column of tracheid (Ikeda 1996, Kuroda *et al.* 1988). As a result, trees begin to wilt (Fukuda 1997) and to be infested with fungi such as the genera *Ceratocystis* and *Diplodia* (Kobayashi *et al.* 1975). The nematode population increases on the fungi in an accelerated manner (Kobayashi *et al.* 1975).

The adult females of pinewood nematode lay eggs after copulation (Mamiya 1975). The first stage juveniles remain in the egg and molt into the second stage. The second stage juveniles emerge from the egg and molt into the third stage propagative or dispersal juveniles. The third stage propagative juveniles molt to the fourth stage propagative juveniles. Third stage dispersal juveniles molt to the fourth stage dispersal juveniles, a special stage for transportation in which the body is packed with droplets of neutral lipids and the mouthparts are without stylet, almost exclusively in the presence of beetle pupae or callow adults (Necibi and Linit 1998, Maehara and Futai 1996, Warren and Linit 1993). Both type of fourth stage juveniles molt to adults.

There is a great variation in virulence of the nematode in the field (Kiyohara and Bolla 1990). Inoculation of the avirulent isolates induces susceptible *P. densifliora* and *P. thunbergii* trees to enhance the systemic resistance to pine wilt disease, which is called the induced resistance (Kiyohara 1984, Kosaka *et al.* 2001). It is unknown if the induced resistance occurs in nature.

Cool summer climate retards the development of pine wilt disease and reduces its incidence (Rutherford *et al.* 1990). Surprisingly, when the pinewood nematode was inoculated on susceptible *P. sylvestris* trees, some trees were found to carry the nematode population between 2 to 11 years without showing any external symptom of pine wilt disease in Vermont, USA (Bergdahl and Halik 1999).

3. BIOLOGY OF INSECT VECTORS

Adult cerambycid beetles of the genus *Monochamus* transport the pinewood nematode (Linit 1988). Insect vectors recorded so far are *M. alternatus* and *M. saltuarius* in East Asia, *M. carolinensis*, *M. mutator, M. scutellatus* and *M. titillator* in North America, and *M. galloprovincialis* in Portugal (Linit 1988, Sato *et al.* 1987, Sousa *et al.* 2001). Most vector species have a one-year life cycle. Some species, however, are known to show a variation in life cycle. *Monochamus alternatus* requires one or two years to complete the life cycle depending on the time of oviposition in Japan (Togashi 1989a) whereas it has two or three generations a year in subtropical area of China (Song *et al.* 1991). In Japan, cool summer temperature increases the proportion of two-year-life cycle, resulting in a reduced rate of reproduction. *Monochamus calorinensis* has uni- and bivoltine life cycles in the United States (Alya and Hain 1985, Pershing and Linit 1986). Their hosts are the family Pinaceae, especially the genus *Pinus*.

In the case of *M. alternatus*, the most important vector in East Asia, the adult beetles emerge from dead host trees and feed on twig bark of healthy host trees. Mean post-emergence longevity is about 1.5 months (Togashi and Magira 1981). Cool temperature reduces the lifetime for the adult (Jikumaru and Togashi 2000). They mature reproductively after one to several weeks. Mature adults locate dying, recently killed, or newly cut pine trees for the oviposition and copulation. The mean fecundity is 86.2 under outdoor conditions (Togashi and Magira 1981). In areas infested with the pinewood nematode, the beetles oviposit on pine-wilt diseased trees in most cases and the outbreak occurs, whereas before the nematode invasion they were a rare species because of limited food resources for the immature stages.

The females excavate the wounds on the bark of the trunk and branches with the mandibles, insert the ovipositor under the bark through the wound, and then deposit the eggs. The larvae feed on the inner bark. When they grow, they form a shallow I-shaped hole and enter the xylem. They construct L- or U-shaped tunnel as refuge in xylem but continue to feed on the inner bark. Before the end of autumn well-developed larvae plug the entrance of U-shaped tunnel with fibrous wooden shreds and occupy an enlarged portion of the tunnel called pupal chamber at the terminal. Poorly developed larvae also do so around the end of autumn or overwinter under the bark (Togashi 1989a). The larvae pupate between late spring and mid-summer, and develop to adults. As the survival rate from egg to adult stage at emergence is as high as 0.249 (Togashi 1990a), the net reproductive rate is estimated to be 10.7 in central Japan.

Adults of *M. alternatus* fly between pine trees. The beetle's mobility increases from the time of emergence to the time of reproductive maturation, at which point it drops (Togashi 1990b). The mean distance transversed per week by immature adults is estimated to be 7.1 to 37.8 m in a pine stand infested with pine wilt disease (Togashi 1990c). Mean transverse distance during the lifetime also is estimated to be 12.3 m for females and 10.6 m for males (Shibata 1986). The proportion of beetles that fly away from the pine stand where they have emerged as adults increases as the stand density decreases (Togashi 1990c). Long-distance dispersal by flight is observed. Marked *M. alternatus* adults are sometimes captured as far as 2 km from the point of release (Fujioka 1992).

4. INFECTION PATHWAYS OF PINEWOOD NEMATODE

The relationship among the nematode, beetle, and pine tree is complicated (Fig. 1). The proportion of third stage dispersal juveniles increases in the dead tree as time elapses. They concentrate around the pupal chambers occupied by beetle larvae or pupae and molt to the fourth stage dispersal juveniles around the time of beetle eclosion. Then they enter the beetle's tracheal system via the openings called spiracles.

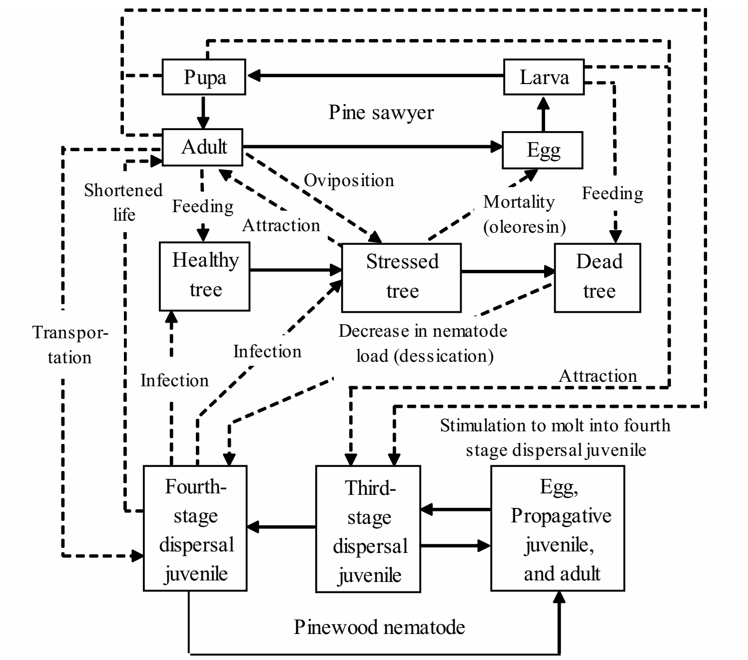

Figure 1. Relationships between the pinewood nematode, insect vector, and *pine tree in pine wilt disease system. Solid* and *broken arrows represent the change of stages or states* and *the action, respectively (modified from Togashi 1989b).*

A majority of nematodes enter through the first abdominal spiracles, during a week-long period prior to the emergence of the adult beetle from the pupal chamber. Most beetles carry fewer than 5,000 nematodes, however, a record 289,000 nematodes were recovered from a single *M. alternatus* (Kishi 1995). After beetle emergence, the fourth stage dispersal juveniles come out of tracheal system via the spiracles, crawl to the beetle abdominal terminal along sterna, and then leave the beetle (Enda 1977). Consequently, beetles of both sexes transmit the nematodes to healthy host trees via the feeding wounds on the twig bark and beetle females transmit them to dying trees via the oviposition wounds directly (Edwards and Linit 1992, Mamiya and Enda 1972, Morimoto and Iwasaki 1972, Wingfield and Blanchette 1983).

A beetle with a great nematode load can transmit enough nematodes to induce the disease during mean time duration of 2-3 day stay on a pine tree (Togashi 1985). However, such beetles are short-lived (Togashi and Sekizuka 1982) although flight performance is scarcely affected by the nematode load (Akbulut and Linit 1999). Togashi (1985) suggested that the nematode divides a beetle population into three functionally different groups; the first group relating to the production of the progeny food, second relating to reproduction, and third with two functions. Cool

temperatures reduce the transmission rate per unit time and retard the time of peak in the transmission (Jikumaru and Togashi 2000).

Other transmission pathways have been found recently. Nematode transmission occurs horizontally between both sexes of beetles through the mating behavior (Edwards and Linit 1992, Togashi and Arakawa 2003). After horizontal transmission, some nematodes re-enter the beetle body and others leave beetle body. Some nematodes that beetle males transmit to females successfully enter the dying tree via oviposition wounds made by the females (Togashi and Arakawa 2003).

More interestingly, beetle males searching for mates transmit the nematodes to dying trees via already existing oviposition wounds on the bark (Arakawa and Togashi 2002). The reason for this is related closely to movement by the nematodes from landing sites to beetle's oviposition wounds. Such infection pathways by mature beetles might contribute to nematode establishment on dying or recently killed trees far from the front of the disease range, which increases the rate of spread.

Roots of different trees sometimes fuse with each other. Using *P. sylvestris* seedlings with roots fused in a pot, the pinewood nematode was found to move from a nematode-inoculated seedling to un-inoculated one (Tamura 1983). It is not known if this transmission pathway is common in nature.

5. WITHIN-STAND PATTERN OF SPREAD

After the invasion of a pine stand by pinewood nematode, the number of diseased trees increases in an accelerated manner, reaches a peak, and then decreases without applying any control measures (Kishi 1995). During a few years of post-invasion, the diseased trees occur at limited sites within a pine stand in the early half of beetle flight season and newly diseased trees in the late half occur surrounding the early diseased ones (Togashi 1991). Early occurrence of diseased trees is considered to be induced by single, sexually immature beetles with a great nematode load and the subsequent occurrence might be due to concentration of mature beetles on early diseased trees. Thus, diseased trees show a clumped distribution with a high degree of aggregation in the early season and low in the late season, resulting from the transmission of nematodes onto surrounding healthy trees by many beetles concentrated (Togashi 1991). After several years of nematode infestation, diseased trees occur all over the stand in the early half of beetle flight season and then they occur surrounding the early diseased trees, showing regular to random distribution at first and then clumped distribution during a flight season. The seasonal increase in the degree of aggregation is explained by the concentration of sexually mature beetles on diseased trees.

6. LOCAL PATTERN OF SPREAD

Long-distance dispersal of the pinewood nematode by beetle flight and the transportation of pine logs infested with the nematode and the insect vector both

accelerate the spread of pine wilt disease. Local spread of the disease from infested pine stands to the surrounding, un-infested pine stands is likely caused by the long-distance dispersal by beetles.

Table 1. Local spread of pine wilt disease in Japan.

Speed (km/ year)	*Study period (years)*	*Prefecture*	*Literature*
3-15	4	Chiba	Matsubara (1976)
4-5	5	Shizuoka (East)	Fujishita (1978)
9-10	5	Shizuoka (west)	Fujishita (1978)
4	3	Aichi	Kato and Okudaira (1977)
2-3	1	Fukuoka	Hagiwara *et al*. (1975)
4.2	9	Ibaragi	Yamamoto *et al*. (2000)

The spread rate of pinewood nematode range over pine stands was determined by the mapping of the front of disease expansion over 9 years (Table 1). The observed values are between 2 to 15 km/ year, resulting in mean of 6 km/ year.

Mathematical models incorporating the reproduction of insect vectors within pine stands and long-distance dispersal of adult vectors estimated that mean spread rate of the front of pine wilt disease is several km/year (Takasu *et al.* 2000, Yamamoto *et al.* 2000). These models used the frequency distribution of distance between beetle release and capture sites obtained by Fujioka (1992).

7. REGIONAL PATTERN OF SPREAD

Long distance transportation of infested pine logs by man is thought to be the primary cause for the regional spread of the pinewood nematode. In South Korea, the nematode was first found in Busan in 1988 and intensive control was started (Fig. 2). The nematode occurred suddenly in Haman 63 km west of Busan in 1997. Then it occurred in Jinju in 1998, Tongyeong in 1999, and Ulsan in 2000 at the distances of 92, 75, and 45 km of Busan, respectively. In 2001, the nematode appeared in six other cities including Mogpo 249 km west of Busan. Almost all causes for the occurrence of the nematode are estimated to be infested logs transported for various usages.

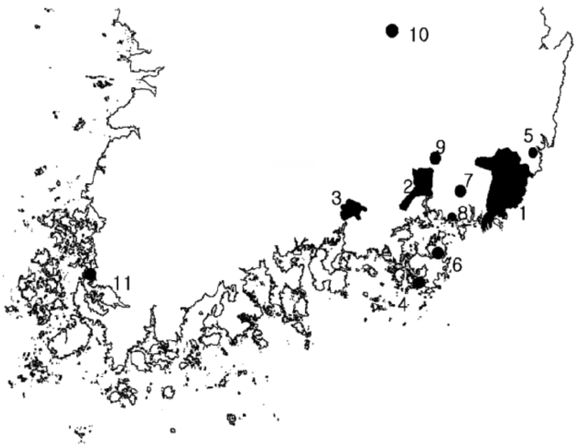

Figure 2. Range of the pinewood nematode infestation in Korea in 2001. Numbers represent the locations where the nematode occurred. 1, Busan (1988); 2, Haman (1997); 3, Jinju (1998); 4, Tongyeong (1999); 5, Ulsan (2000); 6, Geoje (2001); 7, Gimhae (2001); 8, Jinhae (2001); 9, Milyang (2001); 10, Gumi (2001); 11, Mogpo (2001) , where the number in parentheses is year when it was first found.

Though the pinewood nematode was determined to be the causative agent of pine wilt disease in Japan in 1971, *P. thunbergii* and *P. densiflora* tree mortality similar to pine wilt disease occurred first in Nagasaki City, Nagasaki Prefecture in 1905, increased gradually up to 1912, and was eradicated by intensive control shortly after 1912 (Kishi 1995). Pine tree mortality similar to pine wilt disease occurred in Aioi Town, Hyogo Prefecture, 730 km east of Nagasaki City, in 1921 and then in Sasebo City, Nagasaki Prefecture, 50 km away of Nagasaki City in 1925 (Fig. 3). Kishi (1995) estimated the year of invasion of individual prefectures by the nematode based on the records describing disease characteristics of rapid discoloration of foliage to brown, a clumped distribution of tree mortality, and temporal pattern of the increase in tree mortality. According to him, the pinewood nematode introduced into Hyogo Prefecture has spread through all of Japan except the two northernmost prefectures of Aomori and Hokkaido (Fig. 3).

We added records by Akasofu (1974) and Matsueda (1975) to his results. The number of prefectures that had been invaded since the occurrence of pine wilt disease in Hyogo Prefecture increased at an accelerated manner between 1936 and 1947 (Fig. 4). Between 1948 and 1958 the spread was stopped because the army that occupied Japan after World War II recommended the intensive control of pine

wilt disease using a control measure of felling and burning after 1950 (Kishi 1995). After 1959, the number of newly-invaded prefectures increased again and reached 45 in 1982 then stopped increasing (Fig. 4). Now the two northernmost prefectures with the summer cool climate remain to be invaded.

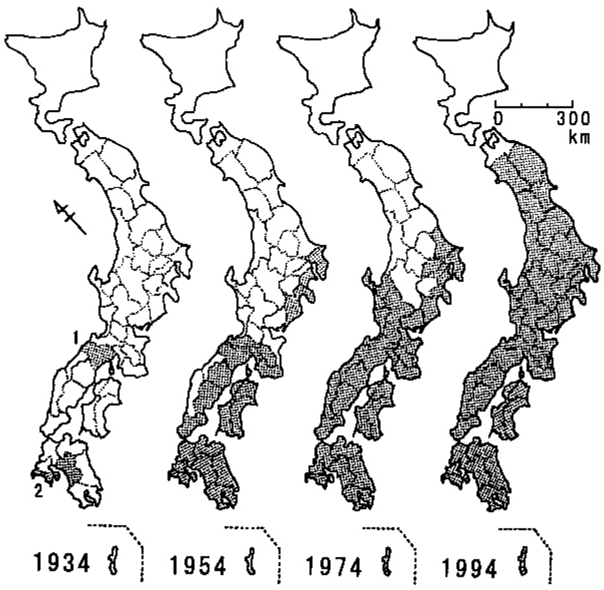

Figure 3. Range expansion of pine wilt disease in Japan. Shaded parts represent prefectures invaded by the pinewood nematode. 1, Hyogo Prefecture; 2, Nagasaki Prefecture.

The number of prefectures, $I(t)$, where pine wilt disease is newly found at year t after the natural infection period decreases as the number of un-invaded prefectures, $U(t)$, prior to natural infection decreases. $I(t)$ increases with the increasing number of prefectures that have a capability of distributing infested pine logs to other prefectures. Thus, let the time delay between the nematode invasion of a prefecture and the distribution to be τ. Consequently,

$$I(t) = pU(t)\left\{\sum_{i=1}^{t-\tau} I(i)\right\} \tag{1}$$

$$U(t) = N - \sum_{i=1}^{t-1} I(i), \tag{2}$$

where N is the total number of prefectures (N =47) in Japan and p is the rate of invasion of un-invaded prefecture by the nematode per year per already-occupied prefecture. By dividing both sides of equation (1) by the number of un-invaded prefectures, we obtain the following equation,

$$I(t) \Big/ \left\{ N - \sum_{i=1}^{t-1} I(i) \right\} = p \left\{ \sum_{i=1}^{t-\tau} I(i) \right\}. \tag{3}$$

Left hand side of equation (3) represents the rate of invasion per un-invaded prefecture and the right hand side represents the rate of transport by already-occupied prefectures. The value of p is estimated by fitting a line passing through the origin to the data. In the case of Japan, we used the data between 1921 and 1947 and those between 1959 and 1982 because of lack of newly-invaded prefectures between 1948 and 1958 (Fig. 5). The value of p is estimated to be 0.0034, 0.0035 and 0.0037 for τ =1, 2 and 3, respectively.

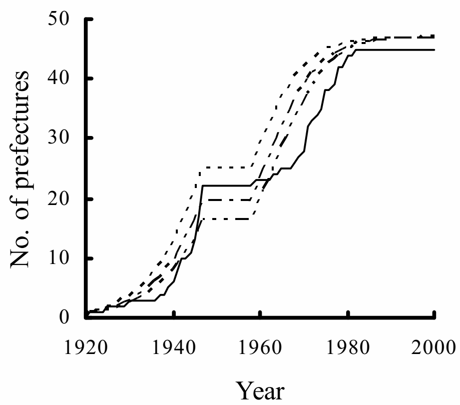

Figure 4. Observed and *simulated changes in the number of prefectures invaded by the pinewood nematode in Japan. The solid line represents the observed data (after Kishi 1995). Broken* and *chain lines with one* and *two dots indicate the results of simulation with p=0.0034* and *τ =1, p=0.0035* and *τ =2,* and *p=0.0037*and *τ =3, respectively.*

Simulation with the values of p and τ showed that it took 2 years for a prefecture to distribute the pinewood nematode to un-invaded prefectures after being invaded (Fig. 4). Close observation indicates that the time delay was more than two years during the periods between 1930 and 1938 and between 1959 and 1967 because the increasing rate of the number of prefectures invaded was observed smaller than simulated one. Adult *M. alternatus* transmits the pinewood nematode to healthy pine trees and then oviposit on diseased trees. Thus, pine wilt disease fails in invasion at very low density of adult beetles (Allee effect) (Yoshimura *et al.* 1999).

The first extended time lag of more than 2 years may have been due to the Allee effect. The late extended time delay may have been due to the intensive control conducted from 1950. Actually, tree mortality decreased between 1950 and 1959 though it increased at an accelerated manner between 1932 and 1937, between 1938 and 1949 and between 1969 and 1979 (Fig. 6) (Furuta 1984). On the other hand, the time delay appeared to be smaller than two years between 1945 and 1947 and between 1970 and 1980.

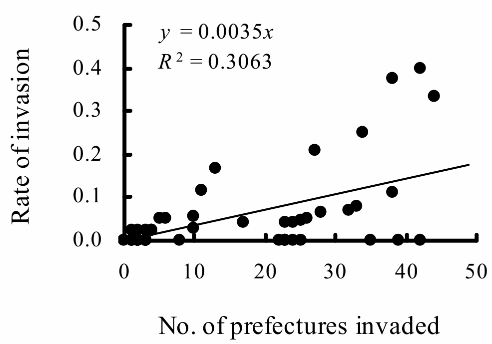

Figure 5. Relationship between the number of prefectures invaded by the pinewood nematode two years or more in the past (τ=2) and *the rate of invasion per year per un-invaded prefecture. A line passing through the origin is fitted to data. The slope gives the estimated value of p.*

To determine the spatial characteristics in the regional spread of pinewood nematode, the diameter of individual prefectures and the focal distance between a newly invaded prefecture and the already-invaded, nearest prefecture were determined following Suarez *et al.* (2001). The diameter of prefectural area was estimated by two times a positive square root of area divided by π. It averages 92.5 km (SD=41.4 km) with the maximum diameter of 326.0 km for Hokkaido and the minimum of 48.9 km for Kagawa Prefecture.

Long-distance dispersal of pine wilt disease was observed five times in Japan according to the above-mentioned criteria; 924 km from Hyogo to Nagasaki

prefectures in 1925, 159 km from Nagasaki to Miyazaki Prefectures in 1939, 416 km from Hyogo to Kanagawa Prefectures in 1941, 648 km from Kagoshima to Okinawa Prefectures in 1973, and 238 km from Ibaragi to Miyagi Prefectures in 1975. This indicates that long-distance dispersal of the disease can occur at any time.

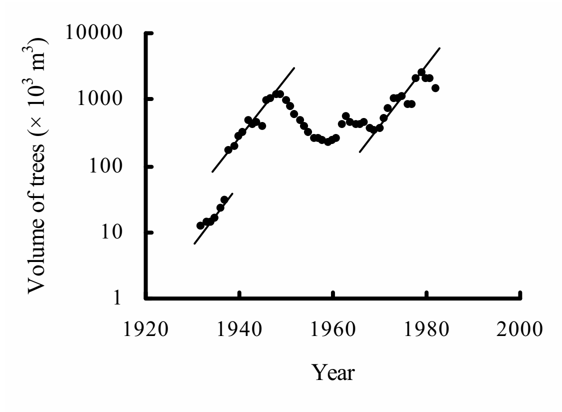

Figure 6. Temporal change in the volume of Pinus densiflora, P. thunbergii, and P. luchuensis *trees killed from the pinewood nematode in Japan (after Furuta 1984). Three lines are fitted to data.*

The distance between a newly-invaded prefecture and the already-invaded, nearest prefecture averaged 125.4 km (SD=161.0 km) with the maximum of 924 km between Hyogo and Nagasaki Prefectures and the minimum of 33 km between Saitama and Tokyo Prefectures. When we considered the already-occupied, nearest prefectures as those that were invaded two years or more in the past, the distance averaged 127.8 km (SD=160.4 km) with the maximum of 924 km and the minimum of 33 km. Consequently, there is no difference in frequency distribution between three distances (Kruskal-Wallis test, H=0.205, P=0.904) (Fig. 7).

8. CONCLUSION

Local and regional spreads of invading organisms has been modeled by reaction-diffusion equations or integrodifference equations incorporating dispersal and reproduction processes when the spread occurs almost exclusively by the movement of the organism or its vector (Andow *et al.* 1990, Shigesada *et al.* 1995, Takasu *et al.* 2000, Veit and Lewis 1996, Yamamoto *et al.* 2000). However, spread dependent on accidental or intended transportation of the organism remains to be analyzed (Suarez *et al.* 2001).

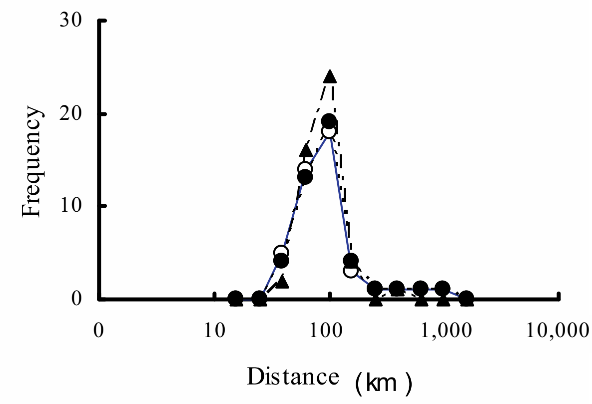

Figure 7. Frequency distributions in diameter of prefecture (▲) and *focal distance between a newly invaded prefecture* and *the nearest prefecture invaded already* (○) *or two years or more in the past* (●).

Using the records in the United States about the Argentine ant that had been detected first in New Orleans in 1891, Suarez *et al*. (2001) showed that the mean distance from a newly invaded county to the already-occupied, nearest county (ca 100 km/ year) was significantly greater than the mean diameter of counties (ca 20 km/ year). This is very different from the case of the regional spread of pine wilt disease in Japan. There are some plausible reasons for this difference. First, mean rate of local spread per year is much smaller for the ant (0.154 km/ year) than the pinewood nematode (6 km/ year). Consequently, the mean time required to transverse an administrative district could be obtained by dividing mean diameter of county or prefecture by mean rate of local spread. The time is much greater for the ant (ca 130 years) than the nematode (ca 15 years). Second, the increase in tree mortality from the pinewood nematode is great even shortly after the invasion of the nematode; tree mortality increased from 6 to 67 during the first two consecutive years in a *P. densiflora* stand of 858 healthy trees without applying any control measures in Ibaragi Prefecture (Kishi 1995).

Transportation of substantial amount of infested logs could begin in a few years of the nematode invasion of pine stand. Third, portions of pine wilt-diseased trees were harvested and kept around houses as fuel up to the 1950's. Also because they maintain their structural intensity, infested trees have been harvested and hauled to lumber mills together with healthy trees to be distributed, for example, to mines, roads and ships for use in construction. Wood chips of infested pine trees were used for pulp industry.

This indicates transportation of infested pine logs within a prefecture and between adjoining prefectures irrespective of ban of transportation of infested logs. Actually, the nematode invaded Okinawa Prefecture by transportation of infested *P.*

thunbergii and *P. densiflora* logs from Kyushu Island and Yamaguchi Prefecture, the most western prefecture of Honshu Island (Kuniyoshi 1974). Great availability of infested pine trees might have decreased the time required for a newly-invaded prefecture to export the nematode to un-invaded prefectures.

9. ACKNOWLEDGEMENT

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10. REFERENCES

Akasofu, Y. 1974. Infestation of *Bursaphelenchus xylophilus* and *Monochamus alternatus* in Toyama Prefecture (I). *Annual Report of the Toyama Prefectural Forest Experiment Station* 9: 82-98.

Akbulut, S. and Linit, M.J. 1999. Flight performance of *Monochamus carolinensis* (Coleoptera: Cerambycidae) with respect to nematode phoresis and beetle characteristics. *Environmental Entomology* 28: 1014-1020.

Alya, A. B. and Hain, F.P. 1985. Life histories of *Monochamus carolinensis* and *M. titillator* (Coleoptera: Cerambycidae) in the piedmont of North Carolina. *Journal of Entomological Science* 20: 390-397.

Andow, D.A., Kareiva, P.M., Levin, S.A. and Okubo, A. 1990. Spread of invading organisms. *Landscape Ecology* 4: 177-188.

Arakawa, Y. and Togashi, K. 2002. Newly discovered transmission pathway of *Bursaphelenchus xylophilus* from male of beetle *Monochamus alternatus* to *Pinus densiflora* trees via oviposition wounds. *Journal of Nematology* 34: 396-404.

Bergdahl, D.R. and Halik, S. 1999. Inoculated *Pinus sylvestris* serve as long-term hosts for *Bursaphelenchus xylophilus*. In K. Futai, K. Togashi and T. Ikeda (Eds.), *Sustainability of Pine Forests in Relation to Pine Wilt* and *Decline* (pp. 73-78). Shokado, Tokyo.

Edwards, O.R. and Linit, M.J. 1992. Transmission of *Bursaphelenchus xylophilus* through oviposition wounds of *Monochamus carolinensis* (Coleoptera: Cerambycidae). *Journal of Nematology* 24: 133-139.

Enda, N. 1977. Boarding of *Bursaphelenchus xylophilus* on *Monochamus alternatus* and its departure from vectors. In *Studies on the control of pine wilt disease* (pp. 83-85). Tokyo: Secretariat of Agriculture, Forestry and Fisheries Research Council, Ministry of Agriculture, Forestry and Fisheries.

Fukuda, K. 1997. Physiological process of the symptom development and resistance mechanism in pine wilt disease. *Journal of Forest Research* 2: 171-181.

Fujioka, H. 1992. A report on the habitat of *Monochamus alternatus* Hope in Akita prefecture. *Bulletin of the Akita Prefecture Forest Technical Center* 2: 40-56.

Fujishita, A. 1978. Infestation of pine wilt disease in Shizuoka Prefecture. *Transactions of the 26th Annual Meeting of Chubu Branch of the Japanese Forestry Society*, pp. 193-198.

Furuta, K. 1984. *Preservation of forests – ecosystem* and *natural control of animals.* Baifukan, Tokyo.

Hagiwara, Y., Ogawa, S. and Takeshita, H. 1975. Range expansion of pine wilt disease. *Transactions of the 28th Annual Meeting of Kyushu Branch of the Japanese Forestry Society*, pp. 153-154.

Ichihara, Y. Fukuda, K. and Suzuki, K. 2000. Early symptom development and histological changes associated with migration of *Bursaphelenchus xylophilus* in seedling tissues of *Pinus thunbergii*. *Plant Disease* 84: 675-680.

Ikeda, T. 1996. Xylem dysfunction in *Bursaphelenchus xylophilus*–infected *Pinus thunbergii* in relation to xylem cavitation and water status. *Annals of the Phytopathological Society of Japan* 62: 554-558.

Ikeda, T. and Kiyohara, T. 1995. Water relations, xylem embolism and histopathological features of *Pinus thunbergii* inoculated with virulent or avirulent pine wood nematode, *Bursaphelenchus xylophilus*. *Journal of Experimental Botany* 46: 441-449.

Ikeda, T. and Suzaki, T. 1984. Influence of pine-wood nematodes on hydraulic conductivity and water status in *Pinus thunbergii*. *Journal of the Japanese Forestry Society* 66: 412-420.

Jikumaru, S. and Togashi, K. 2000. Temperature effects on the transmission of *Bursaphelenchus xylophilus* (Nemata: Aphelenchoididae) by *Monochamus alternatus* (Coleoptera: Cerambycidae). *Journal of Nematology* 32: 110- 116.

Kato, R. and Okudaira, T. 1977. Range expansion of the pinewood nematode in Aichi Prefecture. *Transactions of the 26th Annual Meeting of Chubu Branch of the Japanese Forestry Society*, pp. 159-164.

Kishi, Y. 1995. *The pine wood nematode* and *the Japanese pine sawy*er. Thomas Company, Tokyo.

Kiyohara, T. 1984. Induced resistance in pine wilt disease. In V. Dropkin (Ed.), *Proceedings of the United States-Japan Seminar: The Resistance Mechanisms of Pines against Pine Wilt Disease* (pp. 178-187). Extension Publications, University of Missouri-Columbia, Columbia.

Kiyohara, T. and Bolla, R. 1990. Pathogenic variability among populations of the pinewood nematode, *Bursaphelenchus xylophilus*. *Forest Science* 36: 1061-1076.

Kiyohara, T. and Tokushige, Y. 1971. Inoculation experiments of a nematode, *Bursaphelenchus* sp., onto pine trees. *Journal of the Japanese Forestry Society* 53: 210-218.

Kobayashi, T., Sasaki, K. and Mamiya, Y. 1975. Fungi associated with *Bursaphelenchus lignicolus*, the pine wood nematode (II). *Journal of the Japanese Forestry Society* 57: 184-193.

Kondo, K., Foundin, A., Linit, M., Smith, M., Bolla, R., Winter, R. and Dropkin, V. 1982. Pine wilt disese-nematological, entomological, and biochemical investigations. *University of Missouri-Columbia Agricultural Experiment Station SR282*, pp. 1-56.

Kosaka, H., Aikawa, T., Ogura, N., Tabata, K. and Kiyohara, T. 2001. Pine wilt disease caused by the pine wood nematode: the induced resistance of pine trees by the avirulent isolates of nematode. *European Journal of Plant Pathology* 107: 667-675.

Kuniyoshi, S. 1974. Occurrence of the pinewood nematode in Okinawa Prefecture. *Forest Pests* 23: 40-42.

Kuroda, K., Yamada, T., Mineo, K. and Tmura, H. 1988. Effects of cavitation on the development of pine wilt disease caused by *Bursaphelenchus xylophilus*. *Annals of the Phytopathological Society of Japan* 54: 606-615.

Liebhold, A.M., MacDonald, W.L., Bergdahl, D. and Mastro, V.C. 1995. Invasion by exotic forest pests: a threat to forest ecosystems. *Forest Science Monograph* 30: 1-49.

Linit, M. J. 1988. Nematode-vector relationships in the pine wilt disease system. *Journal of Nematology* 20: 227-235.

Maehara, N. and Futai, K. 1996. Factors affecting both the numbers of the pinewood nematode, Bursaphelenchus xylophilus (Nematoda: Aphelenchoididae), carried by the Japanese pine sawyer, Monochamus alternatus (Coleoptera: Cerambycidae), and the nematode's life history. *Applied Entomology* and *Zoology* 31: 443-452.

Mamiya, Y. 1975. The life history of the pine wood nematode, *Bursaphelenchus lignicolus*. *Japanese Journal of Nematology* 5: 16-25.

Mamiya, Y. 1988. History of pine wilt disease in Japan. *Journal of Nematology* 20: 219-226.

Mamiya, Y. and Enda, N. 1972. Transmission of *Bursaphelenchus lignicolus* (Nematoda: Aphelenchoididae) by *Monochamus alternatus* (Coleoptera: Cerambycidae). *Nematologica* 18: 159-162.

Mamiya, Y. and Kiyohara, T. 1972. Description of *Bursaphelenchus lignicolus* n. sp. (Nematoda: Aphelenchoididae) from pine wood and histopathology of nematode-infested trees. *Nematologica* 18: 120-124.

Matsubara, I. 1976. Observations of the epidemic mortality of pine trees in Chiba prefecture. *Transactions of the 87th Annual Meeting of the Japanese Forestry Society,* pp. 307-308.

Matsueda, A. 1975. Infestation of *Bursaphelenchus xylophilus* and *Monochamus alternatus* in Ishikawa Prefecture. *The Bulletin of the Ishikawa-ken Forest Experiment Station* 6: 43-62.

Morimoto, K. and Iwasaki, A. 1972. Role of *Monochamus alternatus* (Coleoptera: Cerambycidae) as a vector of *Bursaphelenchus lignicolus* (Nematoda: Aphelenchoididae). *Journal of the Japanese Forestry Society* 54: 177-183.

Mota, M.M., Braasch, H., Bravo, M.A., Penas, A.C., Burgermeister, W., Metge, K. and Sousa E. 1999. First report of *Bursaphelenchus xylophilus* in Portugal and in Europe. *Nematology* 1: 727-734.

Necibi, S. and Linit, M.J. 1998. Effect of *Monochamus carolinensis* on *Bursaphelenchus xylophilus* dispersal stage formation. *Journal of Nematology* 30: 246-254.

Pershing, J.C. and Linit, M.J. 1986. Development and seasonal occurrence of *Monochamus carolinensis* (Coleoptera: Cerambycidae) in Missouri. *Environmental Entomology* 15: 251-253.

Rutherford, T.A., Mamiya, Y. and Webster, J.M. 1990. Nematode-induced pine wilt disease: Factorsinfluencing its occurrence and distribution. *Forest Science* 36: 145-155.

Sato, H., Sakuyama, T. and Kobayashi, M. 1987. Transmission of *Bursaphelenchus xylophilus* (Steiner et Buhrer) Nickle (Nematoda, Aphelenchoididae) by *Monochamus saltuarius* (Gebler) (Coleoptera, Cerambycidae). *Journal of the Japanese Forestry Society* 69: 492-496.

Shibata, E. 1986. Dispersal movement of the adult Japanese pine sawyer, *Monochamus alternatus* Hope (Coleoptera: Cerambycidae) in a young pine forest. *Applied Entomology* and *Zoology* 21: 184-186.

Shigesada, N., Kawasaki, K. and Takeda, Y. 1995. Modeling stratified diffusion in biological invasions. *The American Naturalist* 146: 229-251.

Song, S.H., Zhang, L.Q., Huang, H.H. and Cui, X.M. 1991. Preliminary study of biology of *Monochamus alternatus* Hope. *Forest Science* and *Technology* 6: 9-13.

Sousa, E., Bravo, M.A., Pires, J., Naves, P., Penas, A.C., Bonifacio, L. and Mota, M.M. 2001. *Bursaphelenchus xylophilus* (Nematoda; Aphelenchoididae) associated with *Monochamus galloprovincialis* (Coleoptera; Cerambycidae) in Portugal. *Nematology* 3: 89-91.

Suarez, A.V., Holway, D.A. and Case, T.J. 2001. Patterns of spread in biological invasions dominated by long-distance jump dispersal: Insight from Argentine ants. *Proceedings of the National Academy of Sciences of the USA* 98: 1095-1100.

Takasu, F., Yamamoto, N., Kawasaki, K., Togashi, K., Kishi, Y. and Shigesada, N. 2000. Modeling the expansion of an introduced tree disease. *Biological Invasions* 2: 141-150.

Tamura, H. 1983. Infection of pinewood nematode, *Bursaphelenchus xylophilus*, via fused roots. *Transactions of 27th Annual Meeting of Japanese Society of Applied Entomology* and *Zoology*, pp. 163.

Togashi, K. 1985. Transmission curves of *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae) from its vector, *Monochamus alternatus* (Coleoptera: Cerambycidae), to pine trees with reference to population performance. *Applied Entomology* and *Zoology* 20: 246-251.

Togashi, K. 1989a. Development of *Monochamus alternatus* Hope (Coleoptera: Cerambycidae) in relation to oviposition time. *Japanese Journal of Applied Entomology* and *Zoology* 33: 1-8.

Togashi, K. 1989b. Studies on population dynamics of *Monochamus alternatus* Hope (Coleoptera: Cerambycidae) and spread of pine wilt disease caused by *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae). *The Bulletin of the Ishikawa-Ken Forest Experiment Station* 20: 1-142.

Togashi, K. 1990a. Life table for *Monochamus alternatus* (Coleoptera: Cerambycidae) within dead trees of *Pinus thunbergii*. *Japanese Journal of Entomology* 58: 217-230.

Togashi, K. 1990b. Change in the activity of adult *Monochamus alternatus* Hope (Coleoptera: Cerambycidae) in relation to age. *Applied Entomology* and *Zoology* 25: 153-159.

Togashi, K. 1990c. A field experiment on dispersal of newly emerged adults of *Monochamus alternatus* (Coleoptera: Cerambycidae). *Researches on Population Ecology* 32: 1-13.

Togashi, K. 1991. Spatial pattern of pine wilt disease caused by *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae) within a *Pinus thunbergii* stand. *Researches on Population Ecology* 33: 245-256.

Togashi, K. and Arakawa, Y. 2003. Horizontal transmission of *Bursaphelenchus xylophilus* between sexes of *Monochamus alternatus*. *Journal of Nematology* 35: in press.

Togashi, K. and Magira, H. 1981. Age-specific survival rate and fecundity of the adult Japanese pine sawyer, *Monochamus alternatus* Hope (Coleoptera: Cerambycidae), at different emergence times. *Applied Entomology* and *Zoology* 16: 351-361.

Togashi, K. and Sekizuka, H. 1982. Influence of the pine wood nematode, *Bursaphelenchus lignicolus* (Nematoda: Aphelenchoididae), on longevity of its vector, *Monochamus alternatus* (Coleoptera: Cerambycidae). *Applied Entomology* and *Zoology* 17: 160-165.

Yamamoto, N., Takasu, F., Kawasaki, K., Togashi, K., Kishi, Y. and Shigesada, N. 2000. Local dynamics and global spread of pine wilt disease. *Jpapanese Journal of Ecology* 50: 269-276.

Yoshimura, A., Kawasaki, K., Takasu, F., Togashi, K., Futai, K. and Shigesada, N. 1999. Modeling the spread of pine wilt disease caused by nematodes with pine sawyers as vector. *Ecology* 80: 1691-1702.

Veit, R.R. and Lewis, M.A. 1996. Dispersal, population growth, and the Allee effect: Dynamics of the house finch invasion of eastern North America. *The American Naturalist* 148: 255-274.

Warren, J.E. and Linit, M.J. 1993. Effect of *Monochamus calorinensis* on the life history of the pinewood nematode, *Bursaphelenchus xylophilus*. *Journal of Nematology* 25: 703-709.

Wingfield, M.J. and Blanchette, R.B. 1983. The pine-wood nematode, *Bursaphelenchus xylophilus*, in Minnesota and Wisconsin: Insect associates and transmission studies. *Canadian Journal of Forest Research* 13: 1068-1076.

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CHAPTER 12

ALLELOPATHIC EFFECTS OF SOME PLANT SPECIES IN KOREA

1. INTRODUCTION

Allelopathy is an important mechanism of plant interference mediated by the addition of plant-produced phytotoxins to the plant environment and competitive strategy of plants (Muller 1969, Chou and Lin 1976, Rice 1984, Fischer *et al*. 1994, Langenheim 1994). Allelochemicals are released from plant tissue in a variety of ways including emission of volatile substances from living plant parts, exudation from roots, or leaching from above ground parts by rain, dew, fog, etc. (Rice 1984). Many researchers have found that inhibitory substances involved in allelopathy are terpenoids, and phenolic substances (Carballeira 1980, Muller 1965, Kil and Yim 1983, Weidenahmer *et al*. 1994, Seigler 1996).

A wide array of biologically active constituents is produced by plants in the genus *Artemisia* (Marco and Barbera 1990). The volatile essential oil of *Artemisia* species resulted in reduction in seedling survival (Lydon *et al*. 1997, Kil *et al*. 1992).

The volatile oil of *Artemisia afra* has been reported to have several biological activities, notably antibacterial, antifungal and anti-oxidative properties. Monoterpene vapours may cause anatomical and physiological changes in plant seedlings and exposure to volatile terpenes can lead to accumulation of lipid globules in the cytoplasm, reduction in organelles including mitochondria and disruption of membranes surrounding mitochondria and nuclei (Lorber and Muller 1976). The root tip cells subjected to the alkaloids gramine and hordenine caused damages to the cell walls, disorganization of organelles, increase cell vacuoles, and the appearance of lipid and globules, showing food reserves (Liu and Lovett 1993). Large amounts of monoterpene hydrocarbons and/or sesquiterpenes are found to lower the antimicrobial activity of essential oils (Chalchat *et al*. 1997).

Tomato plants are known to exhibit phytotoxic effects (Kim and Kil 1987). Aqueous extracts of leaves, stem and roots of tomato inhibited the germination and seedling growth of test species and the phytotoxicity of the extracts increased with increasing of time of extraction, i.e., 24h < 48h < 72h (Kim and Kil 1987). Bate-Smith (1972) reported the presence of some phenolics in the leaves of tomato plants.

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Tomato plants are aromatic in nature and spread a strong smell into the surrounding environment. Probably, this is due to the presence of some volatile terpenoids which may be responsible for the observed inhibitory effects of tomato plants. Keeping this in mind, the present study was undertaken to (a) verify the presence of volatile inhibitors in the tomato plants and *Artemisia* species in Korea, and (b) identify the chemical substances responsible for the inhibitory effects.

2. ALLELOPATHY IN *Artemisia* SPECIES

2.1 Artemisia princeps var. *orientalis*

Artemisia princeps var. *orientalis* (wormwood) is a major perennial plant around the fields and in mountains in Korea. Other plants do not grow in its proximity. When burnt, it produces a foul smelling smoke, thus it was hypothesized that wormwood contains phytotoxic substances which have harmful allelopathic effects on other plants. Experiments using aqueous extracts of wormwood leaves showed non-significant effects on the receptor species compared with control. In seedling growth tests of lettuce, with abandoned field soils (control) and with soil underneath wormwood plants, the seedlings' growth in soil from under wormwood plants was severely inhibited than control, thereby suggesting release of certain growth inhibitors from wormwood with the inhibitors remaining in the soil (Kil and Yun 1992).

Kil *et al*. (1991) and Kil and Yun (1992) applied different concentrations of aqueous extracts of wormwood to MS 121 media to test the callus induction in lettuce and wormwood. The inhibition in callus growth depended on the concentration of wormwood extracts, the callus growth was suppressed with increase in concentration.

The effects of volatile substances of wormwood were investigated on germination and seedling growth of test spp. The increasing concentration of volatile compounds strongly inhibited the seedling growth over the control, however, sometimes stimulation was also observed (Yun *et al*. 1993). In another study, 5g air-dried wormwood leaves were mixed with 100 g vermiculite and 100 ml Hoagland's solution and incubated for 3,6 and 9 days at 25℃. Thereafter, this mixture was put in the pots and *Lactuca sativa, Achyranthes japonica* and *Artemisia princeps* var. *orientalis* were planted and their seedlings dry weight was recorded. The decomposed wormwood leaf strongly decreased the dry weight of test spp. (Yun and Kil 1989).

The essential oil was extracted from wormwood and its different concentrations were prepared. It was applied to the culture media of *Escherichia coil* and *Bacillus subtilis*, the former grew well but the growth of the later was inhibited at 10 ppm concentration. Its application to mould medium inhibited the growth of *Fusarium solani* and *Aspergillus nidulans* at 100ppm and that of *Pleurotus ostreatus* at 500ppm (Yun *et al*. 1993).

2.2 *Artemisia argyi*

Artemisia argyi leaves and stems were ground to a powder and added 5-30g per litre in a glass chamber to study the effect of volatile substances (Table 1). The volatile substances released from the powdered leaf and stem material decreased the seedling relative elongation ratio (RER) of *Lactuca sativa* seedlings over the control. The stem powder was found more inhibitory than leaf and the inhibition increased with amount of leaf or stem powder (Kil *et al*. 1994).

Tab1e 1. The effect of leaf and stem volatile substances of Artemisia argyi on seedling elongation(mm) of Lactuca sativa sown in glass chamber

Plant part	*Substances (g/1.8)*						
	0	5	10	15	20	25	30
Leaf	14.8^{a}	9.3^{b}	8.3^{bc}	10.0^{b}	9.3^{b}	5.3^{cd}	4.5^{d}
Stem	44.8^{a}	32.3^{b}	34.5^{b}	33.8^{b}	22.0^{b}	22.5^{c}	22.3^{c}

*Homogeneous subsets are displayed at 5% level by Duncan's multiple-range test.

Table 2. Effect of essential oil of Artemisia argyi on callus growth (mg/callus) in MS media supplemented with 1mg/l 2,4-D, 2mg/l NAA and 1mg/l Kinetin in 30 days of culture

Essential oil dose (ul/80ml)	*Pinellia ternate* Breit.		*Oryza sativa* L. cv. Dongjinbyeo	
	Fresh Weight	*Dry Weight*	*Fresh Weight*	*Dry Weight*
0	81.7±16.1 (100)	8.49 ±1.86 (100)	105.5 ±14.2 (100)	10.41 ±1.90 (100)
25	63.9 ±12.0 (84.8)	6.17 ±1.62 (72.7)	72.6 ±17.7 (68.8)	7.33 ±1.53 (70.4)
50	51.3 ±14.1 (62.8)	5.33 ±1.30 (62.8)	35.7 ±11.4 (33.8)	3.32 ±1.03 (31.9)
75	14.2 ±3.7 (17.4)	1.27 ±0.69 (15.4)	23.9 ±10.1 (22.7)	2.22 ±1.15 (21.3)

*The data in parenthesis indicate % of control.

The different concentrations of essential oil of *A. argyi* were applied to culture media, to test the effect on callus growth of *Pinella ternata* and rice W.'Dongjinbeyo'. The essential on decreased fresh and dry weight of callus both in rice and *P. ternata*. The fresh and dry weight of callus decreased with increase in oil concentrations and the reduction was greater in rice than in *P. ternata* (Table 2).

2.3 *Artemisia scoparia*

This perennial spp., *Artemisia scoparia* is dominant in salty coastal areas in western Korea and releases a very strong fragrance. The effect of its aqueous extracts was studied in bioassays on relative germination ratio (RGR) and RER of *Achyranthes japonica*, *Plantago asiatica* and *Atriplex gmelini* test spp. (Table 3).

The extracts had least inhibitory effects on the relative germination ratio (RGR) and growth (RER) of *A*. *gmelini* but caused maximum inhibition in *P. asiatica*. Besides, incre The effects of its volatile substances were also studied on the germination and radicle growth of *A. japonica, P. asiatica* and *A. gmrlini* by keeping 0-30 g leaf powder per litre in a glass chamber. The inhibitory effect of volatiles on RGR and RER followed the order: *P. asiatica* > *A. japonica* > *A. gmelini.* In *P. asiatica,* the volatiles at 20, 25 and 30 g caused more man 90% inhibition in RGR and more than 70% inhibition in RER. The volatiles were least inhibitory to A. *gmelini* (Yoo 1992) asing concentrations of extract proved more harmful to *A. japonica* and *P. asiatica* than *A. gmelini* (Kil and Yoo 1994).

Tab1e 3. Relative germination ratio (RGR) and relative elongation ratio (RER) of selected species tested in Petri dish at different concentration of aqueous extract from Artemisia scoparia Waldst. et Kitamura

Species	*Concentration (%)*				
	10	30	50	70	100
			RGR		
Acyranthes japonica Nakai	98.0	86.3	80.0	60.1	50.2
Plantago asiatica L.	75.5	76.0	58.5	48.0	30.0
Atriplex gmelini Meyer	98.0	97.1	93.5	93.0	85.5
			RER		
Acyranthes japonica Nakai	51.0	48.9	44.8	28.6	25.5
Plantago asiatica L.	68.3	34.1	29.3	12.2	4.9
Atriplex gmelini Meyer	86.5	86.0	82.1	81.0	75.5

2.4 *Artemisia iwayomogi*

Essential oil of *Artemisia iwayomogi* (EOAI) affected the dry weight of receptor plants. The dry weights of all receptor species were inhibited, except *A. princeps* var. *orientalis* and *Oenothera. odorata* (Table 4). Stiles *et al*. (1994) reported that artemisinin and arteannuic acid extracted from *Artemsia annua* inhibited frond production, growth, dry weight and chlorophyll content of *Lemnua*. The 50% inhibition concentration (IC50 value) of germination seedling growth and biomass of receptor plants by E0AI indicated *A. princeps* var. *orientalis* as a sensitive species and *A. japonica* as a tolerant species (Table 5).

2.4.1 *Morphological Changes*

An increasing concentration of essential oil, influenced the root by including lateral root development (data not shown) and intensely decreasing the root hair

length number (Fig. 1). The development of root hair of three receptor plants, *A. japonica*, *P. asiatica* and *R. sativus* var. *hortensis* for. *acanthiformis* exposed to EOAI was compared to the control under the light microscope. Roots treated with 77ppm remarkably showed the reduction of root hair development. Root hair development of *A. japonica*, and *R. sativus* var. *hortensis* for. *acanthiformis* decrease by EOAI remarkable, especially in 39 and 77ppm concentrations. Takahashi (1989) also observed that *Lycoris radiata* allelopathically inhibits the formation of growing radicle tissue of test plants due to radicle hypertrophy by the allelochemicals. At the final stage, atrophy of root was observed. Our results were similar as stated above. *Lactuca sativa*) root growth, but promoted the shoot growth (Inderjit *et al*. 1997).

Table 4. Effects of various concentrations of EOAI on dry weight of receptor plants

	Concentration of essential oil (ppm)				
Receptor Plants	0	19	39	58	77
A.japonica	67.57 ±2.09	43.08 ±14.29**	38.65 ±0.53**	38.09 ±5.08**	34.41 ±8.89**
A.princeps orientalis	9.08 ±1.27	4.83 ±1.22	3.11 ±0.52	2.91 ±1.63	1.49 ±0.33
O.odorata	6.46 ±0.91	6.34 ±1.41	4.34 ±1.69	3.52 ±1.35	3.17 ±0.57
P.asiatica	9.85 ±1.32	5.66 ±0.57**	3.68 ±0.36**	3.76 ±1.35**	2.84 ±0.37**
R. sativus hortensis for *acanthiformis*	253.85 ±41.43	184.41 ±12.75*	164 ±9.03**	140.11 ±32.56**	137.06 ±28.36**

**Means are significantly different according to Scheffe's methods in one way ANOVA (*P<0.05 **:P<0.01).*

Table 5. IC50 values of receptor plants exposed essential oil of Artemisia iwayomogi

Receptor Plant	*IC50 (Essential oil, ppm)*				
	Germin -ation	*Shoot growth*	*Root growth*	*Fresh weight*	*Dry weight*
A.japonica	-*	-	54.6	-	-
A.princeps orientalis	-	76.5	71.2	45.0	35.4
O.odorata	-	-	73.8	65.0	70.0
P.asiatica	-	-	-	57.7	41.5
R. sativus hortensis for *acanthiformis*					

**Means are significantly different according to Scheffe's methods in one way ANOVA (*P<0.05; **:P<0.01).*

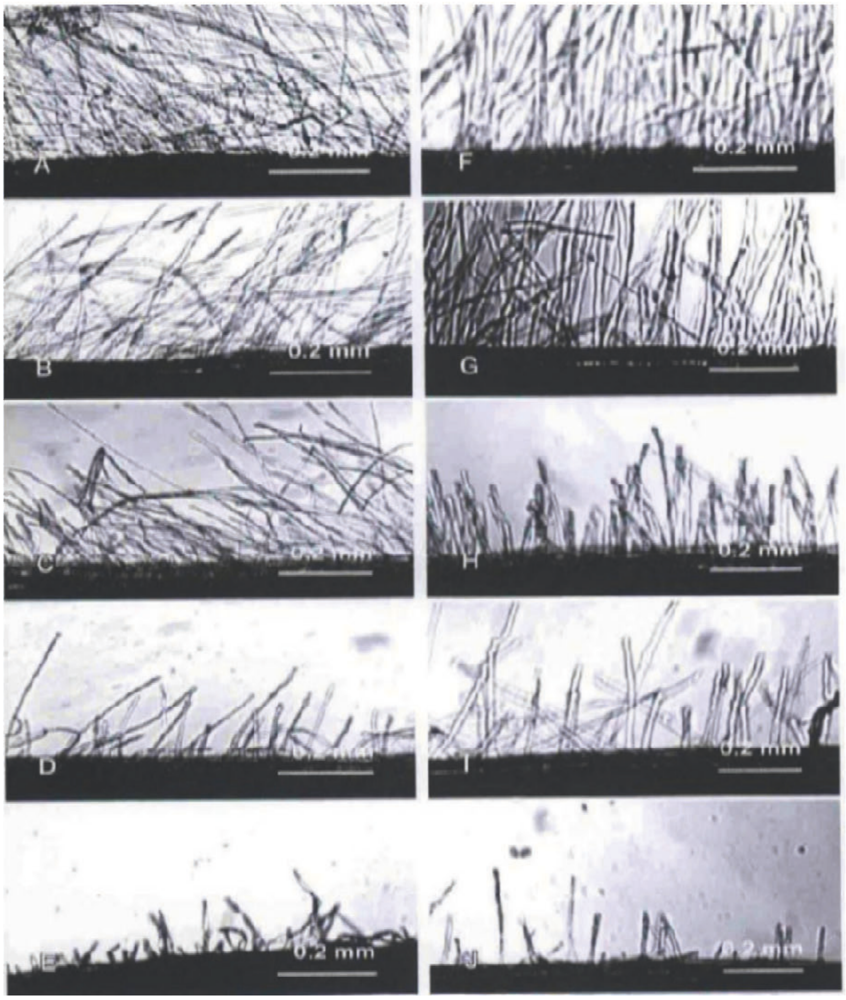

Figure 1. Effect of EOAI on the root hair development of Achyranthes japonica (A-E) and Raphanus sativus var. hortensis for. acanthiformis (F-J). Concentrations of essential oil (ppm) : A,F=control; B,G=19ppm; C,H=39ppm; D,I= 58ppm and E,J=77ppm

The 39ppm EOAI treated root tip cells of *A. Japonica* as seen in electron microscope showed development of remarkable wavy-form cell wall and intercellular spaces (Fig. 2-K, L). Vacuoles in the cells were abundantly fragmented in cytoplasm (Fig. 2-K). The cells accumulated starch gain and lipid droplets. Numerous dictyosome and endoplasmic reticulum were observed in cytoplasm (Fig. 2-L). Aliotta *et al*. (1993) have also observed that cells of radish root treated with

coumarin were highly vacuolated compared to control. Treated cells also contained greater quantities of lipid granules than control cells, with more pronounced vacuolation. Lorber and Muller (1976) suggested that these lipid globules may arise through abnormal metabolism within terpene-treated seedlings, either as a result of poor utilization of nutrients or as a result of the blocking of a metabolic pathway by the allelochemicals. They also suggested that these lipids may be decomposition by-products from organells and membranes. Similar alterations were observed in present study of *A. japonica* by essential oils of four *Artemisia* (Fig. 2). In a previous study (Flaburiari and Kristen 1996, Tarayre *et al*. 1995), it was demonstrated that herbicides (chlorosulfuran and metsulfuron methyl), applied to *in vitro* germinating seeds of maize, caused root ultrastructural changes such as irregularly formed cell walls. These changes or shown in Figure 2 were similar to the above results as our study showed wavy-form cell wall.

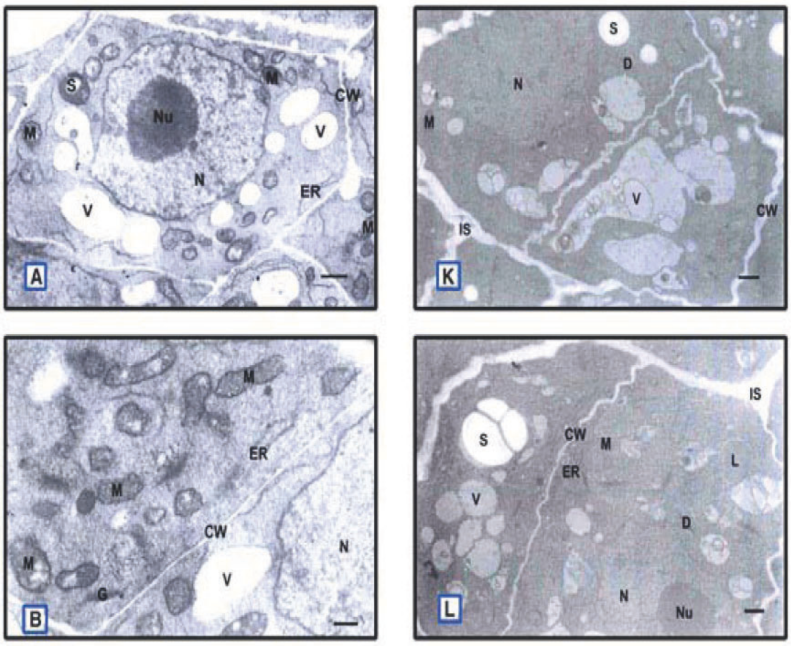

Figure 2. Electron micrographs of root meristematic cell of A. japonica, control (A,B). EOAI treated (K,L). Scale bar =0.5 μm. The control (A,B): Plasma membranes attached to the cell walls (CW) closely and well-developed mitochondria (M) (Scale bar=0.5 μm). The treated (K, L): Wavy-form cell walls, developed intercellular space, and abundantly fragmented vacuoles were appeared (K). Numerous starch grains, lipid droplets, dictyosome and endoplasmic reticulum were observed (L). Scale bar =0.8 μm.

2.4.2 *Identification of Allelochemicals*

The identification of the compounds by GC and GC/MS analyses was based on comparison of their retention times with those of authentic samples and/or by comparison of their mass spectra. In the EOAI, 7 compounds were identified as camphene, *p*-cymene, 1,8-cineole, camphor, 1,3-cyclopentadiene, 1-borneol and β -elemene. EOAI showed 31.8%, 1,8-cienole as a main component. The oil of *Artemisia austriaca* contained, as main components, camphor (45.5%), 1,8-cineol (30.4%), camphene (6,5%), α -terpineol (3.2%), α -pinene (3.O%) and terpinen-4-ol (2.9%) (Guvenalp *et al*. 1998).

2.4.3 *Bioassay with Commercial Compounds*

Two standard compounds which occurred in essential oil of *A. iwayomog*i were used for the bioassay. These compounds exhibited drastic inhibitory effects on seed germination, seedling growth and biomass (Table 6). Among standard chemicals used in bioassay, 1,8-cineole, as a main component, was most toxic inhibitory in seed germination, seedling growth and biomass, followed by camphor. The inhibitory effects were proportional to their concentration.

The allelopathic effects of certain phenolics and terpenoids were accomplished as bioassay. The tested allelochemicals contained 1,8-cienole that inhibited lettuce (*Lactuca sativa*) root growth, but promoted the shoot growth (Inderjit *et al*. 1997).

3. ALLELOPATHY IN TOMATO PLANTS

Aqueous extracts and leachates of tomato (*Lycopersicon esculentum*) plants inhibited the germination and seedling growth (dry weight) of *Celosia cristata*, *Rumex japonicus* and *Allium fistulosum* plants (Kim and Kil 1984). It was observed that when tomato plants are grown in pairs with different plant spp. in U-tube pot, the allelochemicals released from tomato roots inhibited the shoot length and dry weight of crops of *Brassica campestris* var. *perkinensis, Sorghum bicolor, Perilla frutescens* var. *japonica* and Z*ea mays* grown on the other side of U tube pot (Kim and Kil 1987) (Table 7). Besides, the volatile substances released from the tomato plants suppressed the dry weight in lettuce and elongation and dry weight in grapevine planted near the tomato plants.

Shoot length and dry weight of same species pairs viz., *B. campestris* var. *perkinensis* - *B*. *campestris* var. *perkinensis* grown in U tube pot etc. showed little difference between the two paired species, but different species viz. *L. esculenturm* - *Z. mays* etc. grown in pairs showed greater difference between the paired species. GII of shoot length of different species pair was more than the same species pair.

The aqueous extracts of chrystanthemum decreased the germination and dry weight of *Callisterphus chinensis* , *Petunia hybrida* and *Celosia cristata* plants (Kil

and Lee 1987) upto 36 and 60% as compared to plants were inhibitory to germination and growth of test plant spp. Gas chromatography of the essential oils extracted from tomato plants exhibits the presence of 40 components of diverse chemical nature such as alkane, alcohol, aldehyde, ester, carboxylic acid, phenol, terpenoid, ketone, epoxide and tricosine. The major constituents of leaf essential oil were *trans*-2-hexenal, *cis*-hexen-1-ol, eugenol and hexadecanoic acid (Fig. 3).

Table 6. Bioassay in various concentrations of chemical compounds on seed germination of Achyranthes japonica

Receptor Plants	*Seed Germination (Mean ± S,D)*				
	Concentration of essential oil (ppm)				
	0	*19*	*39*	*58*	*77*
Seed germination					
Camphor	28.00±0.82	25.00±1.00	23.33±1.16*	23.33±2.31*	20.00±1.41**
1,8-Cineole	28.00±0.82	21.00±1.73*	20.33±2.08**	20.33±2.89**	19.33±1.53**
Shoot growth					
Camphor	1.55±0.09	0.92±0.06	0.83±0.09*	0.74±0.14**	0.70±0.03**
1,8-Cineole	1.55±0.09	0.79±0.12**	0.68±0.03	0.66±0.03**	0.55±0.03**
Radicle growth					
Camphor	2.79±0.24	2.47±0.28	2.15±0.35	1.52±0.35**	1.47±0.29**
1,8-Cineole	2.79±0.24	1.59±0.45**	1.11±0.08**	1.09±0.19**	0.93±0.15**
Fresh weight					
Camphor	0.20±0.01	0.13±0.01**	0.13±0.01**	0.12±0.03**	0.12±0.02**
1,8-Cineole	0.20±0.01	0.09±0.01**	0.09±0.02**	0.09±0.02**	0.08±0.02**
Dry weight					
Camphor	53.95±4.53	38.11±0.84**	34.80±1.33**	33.07±0.75**	24.73±5.04**
1,8-Cineole	53.95±4.53	34.45±2.41**	32.09±2.04**	30.83±0.58**	25.67±8.19**

**Means are significantly different according to Scheffe's methods in one way ANOVA (*:P<0.05; **:P<0.01).*

Table 7. Comparative growth of two type of pairs, tomato-test plant and test plants-test, grown in U tube pot

Test crop pairs	*Shoot (cm)*	*GII of length*	*Dry Weight (g)*	*GII of dry weight*
	Tomato-Brassica pair			
Lycopersicon esculentum *Mill.*	*52.00*	*0.64*	*10.38*	*0.82*
Brassica campestris *var.* perkinensis *Makino*	*18.50*		*1.86*	
Brassica campestris *var.*	*21.50*	*0.14*	*0.67*	*0.25*

perkinensis *Makino*				
Brassica campestris *var.* perkinensis *Makino*	*25.00*		*0.50*	
			Tomato-Sorghum pair	
Lycopersicon esculentum *Mill.*	*45.70*	*0.21*	*10.09*	*0.89*
Sorghum bicolor *Moench*	*36.00*		*1.07*	
Sorghum bicolor *Moench*	*30.00*	*0.14*	*0.86*	*0.19*
Sorghum bicolor *Moench*	*35.00*		*1.06*	
			Tomato-Perilla pair	
Lycopersicon esculentum *Mill.*	*39.70*	*0.45*	*7.47*	*0.90*
Perilla frutescens *var*. japonica *Hara*	*22.50*		*0.71*	
Perilla frutescens *var*. japonica *Hara*	*22.00*	*0.14*	*0.41*	*0.02*
Perilla frutescens *var*. japonica *Hara*	*19.00*		*0.40*	
			Tomato-Zea mays pair	
Lycopersicon esculentum *Mill.*	*41.10*	*0.27*	*7.60*	*0.84*
Zea mays *Steud.*	*30.60*		*1.20*	
Zea mays *Steud.*	*40.70*	*0.11*	*2.51*	*0.17*
Zea mays *Steud.*	*45.50*		*2.08*	

*GII =Growth superior-growth inferior/growth superior x 100

Based on this authentic samples of α -terpineol, linalool, eugenol and tetradecanoic acid were tested using *Amaranthus mangostanus* as a bioassay plants. Seed germination of *A. mangostanus* was reduced at all the tested concentration of pure chemicals and the inhibitory effect increased with increasing concentration of oil (Table 8).

The results clearly show that tomato plants release volatile substances that act as growth inhibitors. The germination, growth, and dry weight accumulation of the plants grown in vicinity of tomato was reduced. However, the degree of toxicity was dependent on the receptor plant and concentration.

These findings are in agreement with those of Halligan (1976), Heisey and Delwiche (1983), Olesek (1987), Putnam (1988), Yun (1990). Kim and Kil (1987) reported that aqueous extracts from tomato leaves, roots, and plants are highly toxic and later on they identified five phenolic acids, viz., tannic acid, hydroquinone, *p*-hydroxybenzoic acid, vanillic acid and ferulic acid from tomato leaves by HPLC (Kim and Kil, 1989). Phenolic compounds are a main inhibitor of germination and seedling growth (Olmsted and Rice 1970, Whittaker and Feeny 1971, Tinnin and Muller 1972, Horsley 1977, Carballeira 1980). In the present study essential oils from the tomato leaves were found to contain forty components. Among them *trans*-2-hexenal, *cis*-hexen-1-ol, *trans*-2-hexen-1-ol, eugenol and hexadecanoic acid were the major constituents. These were found to be very toxic against *A. mangostanus.* Such an observation is not new, as a number of reports are available in literature which point to the presence of active volatile components in the plants responsible

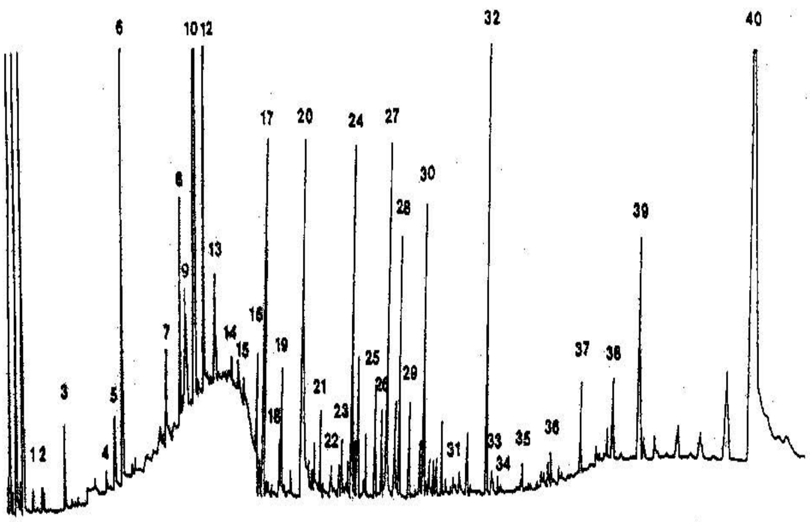

Figure 3. Gas chroamtograms of essential oil of tomato leaf. Keys to number; 1, Methylbenzene; 2, Decane; 3, Hexanal; 4, Dodecane; 5, iso-Amylalcohol; 6, trans-2-Hexenal; 7, 1-Hexen-3-ol; 8, n-Hexanol; 9, cis-3-Hexenyl acetate; 10, cis-Hexen-l-ol; 11, Tetradencane; 12, trans-2-Hexen-1-ol; 13, Linalooloxide; 14, Acetic acid; 15, Pentadecane; 16, Benzaldehyde; 17, Linalool; 18, Hexadecane; 19, β -Caryophyllene; 20, Phenylacetaldehyde; 21, α -Terpineol; 22, Methylbenzoate; 23, Ethylphenylacetate; 24, Methyl salicylate; 25, Geraniol; 26, Guaiacol; 27, Benzylalcohol; 28, 2-Phyenylethylalcohol; 29, β -Caryophyllene epoxide; 31, Heneicosane; 32, Eugenol; 33, Thymol; 34, Docosane; 35, Tricosine; 36, Tetracosane; 37, Pentacosane; 38, Hexacosane; 39 Tetradecanoic acid; 40, Hexadecanoic acid, Components are listed only if their presence was confirmed by mass spectral analysis.

Table 8. Effect of α -terpineol, linalool, eugenol and tetradecanoic acid on germination of Amaranthus mangostanus.

Compound	*Concentration (ppm)*					
	control	*10*	*20*	*30*	*40*	*50*
α -terpineol	59ab	44v	43ab	42b	41b	40b
Linalool	60a	40b	42b	30c	28c	20c
Eugenol	80a	51ab	47bc	40bc	40bc	23c
Tetradecanoic acid	83a	80ab	60bc	60bc	60bc	50c

**Values followed by the different letters in a row are significantly different at $p < 0.05$*

for their phytotoxic/inhibitory effects (Muller 1965, Weaver and Klarich 1977, Kil 1992 Weidenhamer *et al*. 1994). As regards the mode of action of these volatile allelochemicals very few studies are available. Muller (1965) observed that terpenes reduce cell division and elongation leading to reduced growth of cucumber radicle and hypocotyl. Kohli *et al*. (1998) reported that volatile oils from *Eucalyptus* spp. reduced the chlorophyll content and respiratory activity in *Parthenium hysterophorus*. It is, therefore, concluded that tomato plants exhibit allelopathy due to the presence of volatile chemical substances.

4. REFERENCES

Aliotta, G., Cafior, G., Firention, A. and Strumia, S. 1993. Inhibition of radish germination and root growth by coumarin and phenylpropanoids. *J. Chem. Ecol.* 19: 175-483.

Bate-Smith, E.C. 1972. Attractants and repellents in higher animals. In J.B. Harborne (ed.) *Phytochemical Ecology* (pp. 45-56). Academic Press, New York.

Carballeira, A. 1980. Phenpic inhibitors in *Erica australis* L. and associated soil. *J. Chem. Ecol*. 6: 593-596.

Chalchat, J.C., Garry, R.P., Menut, C., Lamaty, G., Malhuret, R. and Chopineau, J. 1997. Correlation between chemical composition and antimicrobial activity. VI.-Activity of some Africa essential oils. *J. Essential. Oil Res*. 9: 67-75.

Chou, C.H. and Lin, H.J. 1976. Autointoxication mechanism of *Oryza stiva.* I. Phytotoxic effects of rice residues in soil. *J. Chem. Ecol* 2: 353-367.

Fischer, C.H., Williamson, G.B., Weidenhamer, J.D. and Richardson, D.R. 1994. In search of allelopathy in the Florida scrub: the role of terpenoids. *J. Chem. Ecol* 20: 1355-1380.

Flaburiari, A. and Kristen. 1996. The influence of chlorosulfuron and metsulfuron methy on root growth and on the ultrastructure of root tips of germinating maize seeds. *Plants and Soil* 180: 19-28.

Guvenalp, Z., Caker, A., Harmandar, M and Gleispach, H. 1998. The essential oils of *Artemisia austriaca* Jacq. and *Artemisia spicigera* C. Koch. from Turkey. *Flavour and Gtangrance Journal* 13: 26-28.

Halligan, J.P. 1976. Toxicity of *Artemisia californica* to four associated herb species. *Amer. Midl. Nat.* 95: 406-421.

Heisey, R.M. and Delwiche. 1983. A survey of California plants for water-extractable and volatile inhibitors. *Bot. Gaz.* 144: 382-390.

Horsley, S.B. 1977. Allelopathic interference among plants. II. Physiological modes of action. In H.E. Wilcox and A.F. Hamer (eds.), *Proceedings of the fourth North American Forest Biology Workshop* (pp. 93-136). Syracuse, State University of New York.

Inderjit, Muramatsu, M. and Nishimura, H. 1997. On the a1lelopathic potential of certain terpenoids, phenolics, and their mixtures, and their recovery from soil. *Can. J. Bot*. 75: 888-891.

Kil, B.S. 1992. Effect of pine allelochemicals on selected species in Korea. In S. J. H. Rizvi and V. Rizvi (eds.), *Allelopathy: Basic and Applied Aspects* (pp. 205-242), Chapman and Hall, London.

Kil, B.S., Kim, Y.S. and Yun, K.W. 1991. Allelopathic effects of growth inhibitors from *Artemisia princeps* var. *orientalis. Kor. J. Ecol*. 14: 121-136.

Kil, B.S. and Lee, S.Y. 1987. Allelopathic effects of *Chrysanthemum morifolium* on germination and growth of several herbaceous plant. *J. Chem. Ecol*. 13: 299-308.

Kil, B.S., Yun, K.W. and Lee, S.Y. 1992. Influence of *Artemisia princeps* var. *orientalis* components on callus induction and growth. *J. Chem. Ecol.* 18: 455-462.

Kil, B.S., Yun, K.W., Lee, S.Y. and Han, D.M. 1994. Influence of chemicals from *Artrmisia argyi* on the growth of selected species of plants and micro-organisms. *Kor J Ecol*. 17: 23-35.

Kil, B.S. and Yim, Y.J. 1983. Allelopathic effects of *Pinus densiflora* on undergrowth of red pine forest. *J. Chem. Ecol.* 9: 1135-1151.

Kil, B.S. and Yoo, H.G. 1994. Phytotoxic effects of *Artemisia scoparia* on the growth of selected species. *J. Nat. Sci., Wonkwang Univ.* 13: 140-145.

Kil, B.S. and Yun, K.W. 1992. Allelopathic effects of water extracts of *Artemisia princeps* var. *orientalis* on selected plant species. *J. Chem. Ecol.* 18: 39-51.

Kim, Y.S. and Kil, B.S. 1984. The effects of aqueous extracts of tomato on germination and seedling growth of different species. *J. Nat. Sci., Wonkwang Univ.* 3: 53-57.

Kim, Y.S. and Kil, B.S. 1987. A bioassay on susceptivity of selected species to phytotoxic substances from tomato plants. *Kor. J. Bot*. 30: 59-67.

Kim, Y.S. and Kil, B.S. 1989. Identification and growth inhibition of phytotoxic substances from tomato plants. *Kor. J. Bot* 32: 41-49.

Kohli, R.K., Batish D.R. and Singh, H.P. 1998. Eucalypt oils for the control of parthenium (*Parthenium hysterophorus* L>). *Crop Protection* 17: 11-122.

Langenheim, J.H 1994. Higher plant terpenoids: a phytocentric overview of their ecological roles. *J. Chem. Ecol.* 20: 1223-1280.

Liu, D.L. and Lovett, J.V. 1993. Biologically active secondary metabolites of barley. II. Phytotoxicity of barley allelochemicals. *J. Chem. Ecol*. 19: 2231-2244.

Lorber, P. and Muller, W.H. (1976). Volatile growth inhibitors produced by *Salvia leucophylla*: Effects on seedling root tip ultrastructure. *Amer. J. Bot*. 63: 196-200.

Lydon, J., Teasdale, J.R. and Chen, P.K. 1997. Allelopathic activity of annual wormwood (*Artemisia annua*) and the role of Artermisin. *Weed Science* 45: 807-811.

Marco, J.A. and Barbera, O. 1990. Natural products from the genus *Artemisia*. *Stud. Nat. Prod. Chem*. 7: 201-264.

Muller, W.H 1965. Volatile materials produced by *Salvia leucophylla*: effect on seedling growth and soil bacteria. *Bot. Gaz*. 126: 195-200.

Muller, C.H. 1969. Allelopathy as a factor in ecological process. *Vegetatio* 18: 348-357.

Oleszek, W. 1987. Allelopathic effects of volatiles from some *Cruciferae* species on lettuce, barnyard grass and wheat growth. *Plants and Soil* 102: 271-274.

Olmsted, C.E. and Rice, E.L. 1970. Relative effects of known plant inhibitors on species from first two stages of old field succession. *Southwestern Naturalist* 15: 165-173.

Putnam, A.R. 1988. Allelochemicals from plants as herbicides. *Weed Technol*. 2: 510-519.

Rice, E.L. 1984. *Allelopathy*. 2nd edition. Academic Press, New York.

Seigler, D.S. 1996. Chemistry and mechanism of allelopathic interaction. *Agronomy Journal* 88: 876-885.

Stiles, L.H., Leather, G.B. and Chen, P.K. 1994. Effects of two sesquiterpene lactones isolated from *Artemisia annua* on physiology of *Lemna monor*. *J. Chem. Ecol*. 20: 969-978.

Takahashi, M. 1989. Mechanism of the allelopathic action of *Lycos radoata* and basis of its use in weed control. In C.H. Chou and G.B. Waller (eds.), (pp. 293-302). *Phytochemical ecology: allelochemical, mycotoxins and insect pheromones and allomones*. Institute of Botany, Academia Sinica, Taipei.

Tarayre, M., Thompson, J.D., Escarr, J. and Linhart, Y.B. 1995. Intra-specific variation in the inhibitory effects of *Thymus vulagris* (Labiatae) monoterpenes on seed germination. *Oecologia*, 101: 110-118.

Tinnin, R.O. and Muller, C.H. 1972. The allelopathic influence od *Avena fatua*: The allelopathic mechanism. *Bull. Torrey Botanical Club* 99: 287-292.

Weaver, R. J. and Klarich. 1977. Allelopathic effects of volatile substances from *Artemisia tridentata* Nutt. *Amer. Midl. Nat.* 97: 508-512.

Weidenhamer, J.D., Menelaou, M., Macias, F.A., Fischer, N.H., Richardson, D.R. and Williamson, G.B. 1994. Allelopathic potential of menthofuran monoterpens from *Calamintha ashei*. *J Chem. Ecol*. 20: 3345-3359.

Whittaker, R.H. and Feeny, P.P. 1971. Allelochemical: chemical interaction between species. *Science* 171: 757-770.

Yoo, H.G. 1992. *Alelopathic potential of natural chemical substances in Artemisia scoparia on selected species.* MS Thesis. Wonkwang University. Iri, Korea.

Yun, K.W. 1990. *Allelopathic effects of chemical substances in Artemisia princeps var. orientalis on selected species*. PhD Dissertation. Wonkwang University, Iri, Korea.

Yun, K.W. and Kil, B.S. 1989. Phytotoxic effects on selected species by chemical substances of *Artemisia princeps* var. *orientalis*. *Kor. J. Ecol*. 12: 161-170.

Yun, K.W. and Kil, B.S. and Han, D.M. 1993. Phytotoxic and antimicrobial activity of volatile constituents of *Artmisia princeps* var. *orientalis.* *J. Chem. Ecol*. 19: 2757-2766.

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CHAPTER 13

BIOMARKERS IN ENVIRONMENTAL MONITORING AND ITS APPLICATION IN *CHIRONOMUS* SPP.

1. INTRODUCTION

In many developed countries, the enforcement of specific regulations had a significant positive effect on the level of environmental pollution in the last decades, especially through a reduction in point source pollution (*e.g.* building of sewage treatment plants) and the ban of some persistent chemicals (*e.g.* DDT, toxaphene). However point source pollution is still a matter of concern in numerous countries and non-point source pollution by organic (*e.g.* pesticides, dioxins) and inorganic (*e.g.* heavy metals) compounds is still a matter of concern worldwide.

The assessment of environmental quality implies that the biological effects of pollutants could be monitored using adapted tools. Ecotoxicology is a multidisciplinary science which focus on the adverse effects of toxicants at various levels of biological organization and which may provide such tools. Ecotoxicological researches have first been devoted to the study the effects of environmental contaminants at the population, community or ecosystem levels (Forbes and Forbes 1994). However, these traditional approaches are sometimes inefficient, especially to adequately assess the effects of chronic exposure of organisms to low levels of xenobiotics and to detect early biological responses. Therefore, there has been a shift in emphasis towards understanding the sublethal effects of long-term exposure to contaminants at the individual level where exposure can be adequately described and assessed (Newman and Jagoe 1996). It has been necessary to perform studies on individuals at the biochemical and molecular levels where toxicant-induced responses are initiated.

The effects of toxicants usually begin through an interaction between toxicants and biomolecules (*e.g.* enzymes, receptors, DNA). Effects then cascade through the molecular, biochemical, subcellular, cellular, tissue, organ, individual, population, community and ecosystem levels of organization. Therefore, the understanding of the effects of toxicants at the molecular or biochemical levels may provide some insights into the cause of effects identified at higher levels (Newman and Unger 2003). The biomarker approach can be an extremely useful tool for this kind of

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investigation and it has been increasingly used for environmental hazard assessment during the last ten years (Delpedge and Fossi 1994, Fossi *et al.* 2000).

2. BIOMARKER-BASED ENVIRONMENTAL MONITORING

2.1. Concept of biomarker

The historical development of the biomarker approach is closely linked to advances in medicine and vertebrate biology (NRC 1987). Biomarker measurements are now equally feasible in many plants and animal species (Livingstone 1991, Depledge and Fossi 1994, Fossi *et al.* 2000, Lagadic *et al.* 2000). Biomarkers were originally defined as xenobiotically-induced variations in cellular or biochemical components or processes, structures or functions that are measurable in a biological system or sample (NRC 1987). They were first classified as markers of exposure to a toxicants, markers of effects of exposure and markers of susceptibility to the effects of exposure (NAS/NRC 1989). This definition has been challenged by several authors (Adams 1990, Engel and Vaughan 1996, McCarty and Munkittrick 1996) and the term biomarker is now more commonly used in a more restrictive sense, namely sublethal biochemical changes resulting from individual exposure to xenobiotics (Hyne and Maher 2003).

The biomarker approach has received considerable attention in ecotoxicology as a new and potentially powerful and informative tool for detecting and documenting exposure to, and effects of, environmental contamination (Newman and Jagoe 1996). The primary use of biomarker in environmental monitoring is to assess the health of organisms in order to detect and identify potential problems so that unacceptable and irreversible effects at higher levels of biological organization can be avoided. It is important, however, to keep in mind that our current understanding of biomarker responses in wild species is limited. To achieve the full potential of this tool for the protection of the environment, a great deal of research is still needed to develop, validate and interpret biomarker based monitoring.

2. 2. Potentials and limitations of biomarker in environmental monitoring

Chemical pollution is often caused by a complex mixture of compounds, which makes the exhaustive analysis of the contaminants present in polluted environment impossible (Risso-de-Faverney *et al.* 2001, Meregalli *et al.* 2002). Moreover, the mere presence of a pollutant does not indicate an impact on organisms, as its bioavailability may be influenced by many factors (see *e.g.* Landrum and Robbins 1990). The use of biomarkers to assess the biological and ecological significance of environmental contaminants is a complementary approach to chemical analysis and is becoming an important component of many environmental monitoring programs. Organisms can provide more complete information on the impacts of the toxicants than chemical analysis alone because some of them can integrate the exposure to

contaminants and respond in some measurable and predictable ways (Vermeulen 1995). Responses can be observed at several levels of biological organization from the biomolecules level, where pollutants can cause damage to critical cellular targets and elicit cellular mechanisms of defense such as detoxication (*e.g.* cytochrome P450 associated enzymatic activities, glutathione *S*-transferases) and repair process (*e.g.* DNA repair enzymes), to the organismal level, where severe disturbances such as impairment in growth, reproduction, developmental abnormalities, or decreased survival may be observed (Newman and Jagoe 1996). Biomarkers can provide not only evidence of exposure to a broad spectrum of anthropogenic chemicals, but also a temporally integrated measure of bioavailable contaminants. A suite of biomarkers should preferably be used to determine the magnitude of the problem at the individual level and evaluate possible consequences at the population or community levels (Cormier and Daniel 1994).

Recently, the growing awareness of the possibility of using wildlife animals as sentinels for human environmentally-induced diseases has created a demand for biomarkers that are nonlethal and correlate with adverse effects in humans (Kendall *et al.* 2001). Links between wildlife and human health can serve as a premise for extrapolation in risk assessment. Indeed, humans share many cellular and subcellular mechanisms with wildlife species. Humans and wildlife also overlap in their environments and may therefore be exposed to the same contaminants. There is evidence to suggest that when highly conserved systems are targeted by environmental toxicants, both ecosystem and human health suffer (Kendall *et al.* 2001).

As biochemical changes are usually detectable before adverse effects may be seen at higher level of biological organization, the biochemical marker approach is often considered as an early warning or proactive tool. This is a great advantage because responses at higher levels are usually measurable only after a significant or permanent damage has occurred. The early detection of sublethal effects may also be used to identify the need for remedial action at a contaminated location and to monitor the recovery period after cleanup of the site (Peakall and Shugart 1993, Depledge and Fossi 1994, Lagadic *et al.* 2000). Regardless of their proactive or retroactive utility, the ecological realism of biomarkers is lower than for indicators based on higher-level of biological organization such as species richness or reproductive failure (Newman and Unger 2003).

The choice of the appropriate biomarker requires an accurate knowledge of a variety of factors (Mayer *et al.* 1992, Peakall and Shugart 1993). Thus, it is critical to use well-defined biological material, for which the changes in biochemical activity with development, age and tissue is known, in order to predict toxicity from changes in biochemical biomarker response following the exposure to a chemical (Hyne and Maher 2003). The selection of biomarkers applicable in many species is frequently limited by a lack of knowledge on their intrinsic characteristics (*e.g.* basal level, feedback control, role of repair mechanisms). The reliability of use of biomarkers depends on knowledge of the mechanism involved in the particular response. Once suitable biomarkers are selected, it is important to conduct field

studies to establish how environmental and biotic factors will modify the biomarker responses to toxicants relative to those seen in laboratory conditions where those factors are controlled (Hyne and Maher 2003).

2.3. Multilevel biomarker based approach

As mentioned above, biomarker responses could be used as an early warning system for environmental monitoring (Peakall and Shugart 1993, Depledge and Fossi 1994, Lagadic *et al.* 2000). Nevertheless, biochemical endpoints alone do not seem to be sufficient to assess environmental quality. Pollutant-induced biochemical effects may potentially have consequences at higher levels of biological organization, such as changes in population dynamics or in biological diversity at both the intra- and interspecific levels (Depledge *et al.* 1993, Caquet and Lagadic 2000). Such changes may have adverse ecological consequences (Caquet and Lagadic 2000). Therefore, multilevel biomarker approach, evaluating different biological responses ranging from molecular to physiological level, would be more conservative for useful environmental monitoring (Depledge and Fossi 1994, Lagadic *et al.* 1994, 2000, Dickerson *et al.* 1994, Choi *et al.* 2002).

The multilevel biomarker concept is originally based on the fact that biological responses of an organism in natural environment progresses through homeostasis, compensatory and repair phases, as the exposure level or duration increases (Depledge 1994). While an organism is exposed to contaminants, physiological compensatory mechanisms become active and changes in physiological processes or functions occur, which indicate that exposure has occurred. If the exposure persists or the level of exposure increases, these compensatory mechanisms become overwhelmed, damages occur, and physiological repair mechanisms become active. Under natural environmental conditions, as an organism progresses through these phases, the energy allocated for natural maintenance is reduced as more energy is needed for compensatory response and repair. The organism weakens and may be quickly eliminated from the population.Therefore, *in situ* survey of populations may not allow to detect diseased organisms even though exposure and effects have occurred (Newman and Jagoe 1996). In the context of the multiple-response paradigm, the objective is not to quantitatively measure the amounts of different toxicants, but to determine where an organism is located on the continuum between homeostasis and disease. Responses indicate whether the organism is challenged but readily coping with toxicant stress (compensatory phase) or is deeply stressed and needs to use its energy resources to repair damages. This approach is essential to determine the general health status of the organism, moreover, it makes possible to extrapolate the relationship between responses at different levels of biological organization (Fossi *et al.* 2000).

Some biochemical biomarkers do not appear to have a direct relationship to a defined mechanism of toxicity. In this case, the use of such biomarker will not give a reliable prediction of toxic effects and is, therefore, only ever likely to indicate exposure to chemicals. These biomarkers of exposure cannot be used to predict

effects at the population level from biomarker changes measured in a sample of individuals (Hyne and Maher 2003). To relate the effects measured at the individual level to higher levels of biological organization, the biomarker response should be related to an impairment of growth, reproduction, or metabolic function which directly affects the survival of the organism and which can be attributed to exposure to a known amount of specific contaminants (Delpedge and Fossi 1994).

3. ENVIRONMENTAL MONITORING USING *CHIRONOMUS* SPP

3.1. Ecotoxicological significance of invertebrate biomarkers

To link the measurement of a biomarker in individuals to changes at the population level, it is necessary to understand the mechanisms, which link the effects at the subcellular level to the response of individuals. Quantitative dose-response relationships for the biomarker may then link the molecular effect of the toxicant to the toxic response of the individual organism. Linkage of whole organism responses to changes in populations can then be obtained by statistical or numerical inferences (Hyne and Maher 2003). Invertebrates are good biological models for such studies. They are major components of all animal communities and they represent 95% of all animal species on Earth (Barnes 1968). Their populations are often abundant and their life cycles are frequently short, so samples can be taken for analysis without significantly affecting population dynamics and population level effects can be examined concomitantly with the response of biomarkers. Increasing knowledge of the biochemistry of invertebrates (James 1989, Livingstone 1991), now permits reasonable interpretation of biomarker responses in terms of ecological risk assessment (Depledge 1994, Depledge and Fossi 1994). Numerous biomarkers are extensively studied in various invertebrates species to evaluate their potential for predicting population level changes. This is for example the case of DNA damage (Deplege 1998, Wilson *et al.* 1998, Atienzar *et al.* 1999, Fossi *et al.* 2000, Guecheva *et al.* 2001), heat shock proteins induction (Snyder and Mulder 2001, Wheelock *et al.* 2002, Guecheva *et al.* in press), energy reserves (Baturo and Lagadic 1996) or of the alteration of the activity of various enzymes (Abele-Oeschger 1996, Baturo and Lagadic 1996, Fossi *et al.* 2000, Hyne and Maher 2003, Guecheva *et al.* in press).

3.2. Particularities of Chironomus as a sentinel invertebrate species

Various factors need to be considered when selecting a species for ecotoxicological monitoring, including knowledge of its physiology and of its demoecology, the availability of laboratory rearing protocols, ... The aquatic larvae of non-biting midges (Chironomidae, Diptera), which are widely used in freshwater environmental monitoring and laboratory toxicity testing, fulfill those criteria. They are ubiquitously distributed, sensitive to many pollutants, easy to culture and have a

short life cycle (Ingersoll and Nelson 1990), which make them suitable for ecotoxicological monitoring.

The midges frequently represent the most abundant group of macroinvertebrates and up to more than 50 % of the total number of macroinvertebrate species in freshwater ecosystems, especially in the profundal and sublittoral zones of lakes. The Chironomidae, and especially the sub-family *Chironominae*, are the most widely distributed group of insects, having adapted to nearly every type of aquatic or semiaquatic environment. The larvae are diverse in form and size, but they are easily recognized because they usually have anterior and posterior pairs of prolegs and a distinct head capsule. Larvae are an extremely important part of aquatic food chains as detritivores and serving as preys for many invertebartes and for several species of fish (see review *in* Cranston 1995).

The chironomid life cycle includes egg, larva, pupa and adult stages (Fig 1). The females lay their eggs in a group as an eggmass (Fig 1A) with up to 800 eggs (in *Chironomus duplex*), either directly into water or attached to plants or stones at the water´s edge. After a couple of days the eggs hatch as larvae, which, in the sub-family *Chironominae*, are usually red-colored due to the presence of hemoglobin in the hemolymph (Fig 1B). The larvae go through four instars. In the fourth instar larvae, polytene chromosomes develop in some tissues (*e.g.* salivary glands), reaching their greatest size just before the larva pupates in a silk-lined tube. The larvae are 2 to 30 mm long, depending on species and larval instar and often exhibit a slightly curved shape, particularly when preserved in alcohol or formalin. The duration of the larval period may range from two weeks to several years and depends mostly on temperature. The pupal stage lasts no more than a few days. After 2 or 3 days the pupa swims to the surface and the adult midge emerges. Usually, the adults live only a day or two, mating in swarms, laying their eggs and then dying. Adult chironomids are minute- (*e.g.* wing length 0.8 mm in *Orthosmittia reyei*) to medium-sized (*e.g.* wing length 7.5 mm in *Chironomus alternans*) insects (Fig 1C, 1D). In temperate regions, many chironomid species are uni- or bivoltine, but up to four generations in a year are not uncommon. Species living in the cold, profundal zones of deep lakes may take more than one year to complete their life cycles, and circumpolar species require at least two years, and occasionally as many as seven (see review *in* Cranston 1995).

A B C D

Figure 1. Chironomid A) egg mass, B) larva, C) female adult, D) male adult

The predictable responses of populations of certain species of midges to different levels of various pollutants have resulted in the use of larval chironomids as biological indicators of water quality. Additionally, chironomid larvae are essential components in the efficient biological processes that take place in the oxidation ponds of sewage treatment plants. Water quality also determines chironomid distribution in the field, and within the family Chironomidae a wide range of tolerance is displayed. Some *Tanypodinae* and *Chironominae* are very tolerant towards low levels of dissolved oxygen. *Chironomus plumosus* larvae are able to withstand a pH value of 2.3. *Cricotopus bicinctus* is known for its tolerance for many substances, including electroplating wastes and crude oil. Other members of the family are known for their intolerance for poor water quality (see review *in* Pinder 1986). Larvae of midges of the genus *Chironomus* are among the rare invertebrate species to possess hemoglobin(s) (Hbs), which give them some biochemical and physiological particularities. *Chironomus* Hbs exhibit many interesting features, such as a high degree of polymorphism, a high affinity for oxygen and an extracellular localization (Osmulski and Leyko 1986). From an evolutionary point of view, it is generally admitted that the presence of Hbs in invertebrates reveals the adaptation of these organisms to unfavorable environmental conditions, since these pigments help to sustain aerobic metabolism under low-oxygen conditions (Weber and Vinogradov 2001). *Chironomus* Hbs appear to fulfill clear physiological roles in transporting and storing oxygen in the larvae that burrow in polluted and hypoxic muds (Osmulski and Leyko 1986). According to Weber (1980) and Lindegaard (1995), the extracellular Hbs enhance the good exploitation of hypoxic oxygen. Moreover, a possible but still undefined role has been proposed for *Chironomus* Hbs in the metabolism of xenobiotics in frequently polluted environments, where these animals flourish (Osmulski and Leyko 1986, Weber and Vinogradov 2001).

3.3. Multilevel biomarkers in Chironomus spp.

The above-mentioned physiological and ecological particularities make chironomid larvae a suitable invertebrate model for biomarker-based environmental monitoring and ecological risk assessment. Biomarkers have frequently been studied in this insect group. Various endpoints, ranging from molecular to population level, have been employed in chironomid for environmental quality assessment, especially for species of the genus *Chironomus* (Tables 1 and 2). Changes of enzyme activities or chromosome-level alterations were mainly used as molecular or biochemical biomarkers (Table 1), whereas development time, life cycle or reproduction performances were investigated as population-level descriptors (Table 2). Most studies have been performed under laboratory condition, and few studies were undertaken in natural ecosystems.

As shown in Tables 1 and 2, despite the increasing use of biomarkers for assessing environmental toxicity, there have been few studies in which effects on biochemical responses have been compared with subsequent effects on individual

fitness or population health. Organisms show homeostatic responses to changes in environmental conditions, and differences in biomarker measurements may be within the usual range of expression and have no long-term significance for organism fitness (Peakall 1994, Olsen *et al.* 2001). Alternately, the responses of biomarkers may only be measurable when obvious damage to the fitness of an organism has occurred, which considerably reduces their usefulness. Therefore, it is clearly important to be able to relate changes in biomarkers to meaningful effects at higher levels of biological organization, and to determine that these changes occur earlier and may truly act as an "early warning" (Depledge and Fossi 1994). This kind of approach has recently been conducted in *Chironomus* (Choi *et al.* 2002, Crane *et al.* 2002).

In the field, chemical pollution often occurs as a complex mixture of pollutants and this may impede the prediction of pollutant effects. In this context, the measure of multiple biological parameters presents several advantages. It is fundamental to accumulate data at different levels of biological organization in order to fully understand the effect of toxicants on organisms.

Table 1. Examples of biomarkers studied in Chironomus spp.

Species	*Stressors*	*Endpoints*	*References*
C. tentans	insecticides	Acetylcholinesterase	Karnak and Collins (1974)
C. riparius	insecticides	Cytochrome P450	Estenik and Collins (1979)
C. riparius	parathion	Acetylcholinesterase	Detra and Collins (1991)
C. ninevah	cooper	Balbiani ring	Aziz *et al.* (1991)
C. tentans	benzo[a]pyrene, actynomycinD, dimethylnitrosamine	Chromosome puffing	Bentivegna and Cooper (1993)
C. salinarius	contaminated sediments	Polytene chromosome	Hudson and Ciborowski (1996)
C. riparius	heavy metals	Polytene chromosome	Michailova *et al.* (1998)
C. tentans	heat shock	Stress protein (hsp70)	Karouna-Renier and Zehr (1999)
C. riparius	fenitrothion, chromium	Antioxidant enzymes	Choi *et al.* (2000)
C. tentans	cadmium	alpha-tubulin cDNA	Mattingly *et al.* (2001)
C. riparius	fenitrothion, chromium	Energy metabolism	Choi *et al.* (2001)
C. riparius	contaminated sediment	Mouthpart deformity / Nucleolus activity	Meregalli *et al.* (2002)
C. riparius	fenitrothion	AcetylcholinesteraseSuperoxide dismutase	Choi *et al.* (2002)
C. riparius	pirimiphos methyl	AcetylcholinesteraseGlutathione *S*-transferase	Crane *et al.* (2002)
C. riparius	aluminium	Polytene chromosome	Michailova *et al.* (2003)
C. riparius	phenobarbital, permethrin	Cytochrome P450	Fisher *et al.* (2003)

Table 2. Examples of the population level effects studied in Chironomus spp.

Species	*Stressors*	*Endpoints*	*References*
C. tentans	DDE	Egg viability	Derr and Zabik (1972)
C. riparius	cadmium	Oviposition /egg viability	William *et al.* (1987)
C. decorus	cooper	Partial life cycle	Kosalwat and Knight (1987)
C. riparius	cadmium	Larval development /adult emergence	Pascoe *et al.* (1989)
C. riparius	aluminum	Life cycle	Palawski *et al.* (1989)
C. riparius	lindane	Life cycle	Taylor *et al.* (1993)
C. riparius	ethynyloestradiol /bisphenolA	Development / reproduction	Watts *et al.* (2001)
C. riparius	hexachlorobiphenyl	Life cycle	Hwang *et al.* (2001)
C. riparius	fenitrothion	Emergence	Choi *et al.* (2002)
C. riparius	pirimiphos methyl	Emergence	Crane *et al.* (2002)
C. riparius	ethynylestestradiol /bisphenolA	Emergence / reproduction	Segner *et al.* (2003)

Furthermore, the measure of population-level parameters may facilitate the interpretation of the data at the lower biological levels (Atienzar *et al.* 1999). *In situ* application of the multilevel biomarkers approach will help develop a better understanding of the ecological consequences of low-level environmental contamination in the field, and *Chironomus* system provides a promising biological model system to address these approaches.

4. CONCLUSION

A fundamental challenge in ecotoxicology is to link the presence of a chemical in the environment with a valid prediction of hazard for biota. A biomarker-based approach may help to resolve this difficulty by providing a direct measure of toxicant effects in the exposed species (Dickerson *et al.* 1994). Understanding molecular and biochemical effects enhances our ability to assign causal linkage to effects at higher levels of biological organization and to predict effects of chemicals based on similar molecular interactions with biomolecules. To better diagnose environmental quality, multilevel biomarkers-based approach, which permits better understanding of the impact of pollutants on organisms, should be implemented in environmental monitoring procedures. Moreover, the interconnections between ecologic heath and human health should not be overlooked. What is needed, in the future, are new and innovative approaches that integrate effects across different levels of biological complexity and provide a clear understanding of all the hazards posed by environmental pollution, not only to ecological systems but for human health as well.

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6. REFERENCES

Abele-Oeschger, D. 1996. A comparative study of superoxide dismutase activity in marine benthic invertebrates with respect to environmental sulphide exposure. *J. Experimental Marine Biology and Ecology* 197: 39-49.

Adams, S.M. 1990. Status and use of biological indicators for evaluating the effect of stress in fish. In S.M. Adams (Ed.), *Biological Indicators of Stress in fish* (pp. 1-8). *American Fisheries Society Bethesda*, MD.

Atienza, F.A., Conradi, M., Evenden, A.J., Jha, A. and Depledge, M.H. 1999. Qualitative assessment of genotoxicity using random amplified polymorphic DNA: Comparison of genomic template stability with key fitness parameters in *Daphnia Magna* exposed to benzo[a]pyrene. *Environmental Toxicology and Chemistry* 18: 2275-2282.

Aziz, J.B., Akrawi, N.M. and Nassori, G.A. 1991. The effect of chronic toxicity of copper on the activity of Balbiani ring and nucleolar organizing region in the salivary gland chromosomes of *Chironomus ninevah* larvae. *Environmental Pollution* 69: 125-130.

Barnes, R.D. 1968. *Invertebrate Zoology*. Sanders, Philadelphia.

Baturo, W. and Lagadic, L. 1996. Benzo[a]pyrene hyroxyrase and glutathion S-transferase activities as biomarkers in *Lymnaea Palustris* (Molusca, Gastropoda) exposed to atrazine and hexachlorobenzene in freshwater mesocosms. *Environmental Toxicology and Chemistry* 15: 771-781.

Bentivegna, C.S. and Cooper, K.R. 1993. Reduced chromosomal puffing in *chironomus thummi* as a biomarker for potentially genetoxic substances. *Environmental Toxicology and Chemistry* 12: 1001-1011.

Caquet, Th. and Lagadic, L. 2000. Consequences of individual-level alterations on population dynamics and community structure and function. In L. Lagadic, Th. Caquet, J. C. Amiard, F. Ramade (Eds.), *Use of Biomarkers in Monitoring Environmental Health.* Balkema, Rotterdam, The Netherlands and Science.

Choi, J., Caquet, Th. and Roche, H. 2002. Multi-level effects of sublethal fenitrothion exposure in *Chironomus riparius* mg. (Diptera, Chironomidae) larvae. *Environmental Toxicology and Chemistry* 21: 2725–2730.

Choi, J., Roche, H. and Caquet, Th. 2001. Hypoxia, hyperoxia and exposure to potassium dichromate or fenitrothion alter the energy metabolism in *Chironomus riparius* Mg. (Diptera: Chironomidae) larvae. *Comparative Biochemistry and Physiology C.* 130: 11-17.

Choi, J., Roche, H. and Caquet, Th. 2000. Effects of physical (hypoxia, hyperoxia) and chemical (potassium dichromate, fenitrothion) stress on antioxidant enzyme activities in *Chironomus riparius* Mg. (Diptera, Chironomidae) larvae: potential biomarkers. *Environmental Toxicology and Chemistry* 19: 495-500.

Cormier, S.M. and Daniel, F.B. 1994. Biomarkers: taking the science forward. *Environmental Toxicology and Chemisty* 13: 1011-1021.

Crane, M, Sildanchandra, W., Kheir, R. and Callaghan, A. 2002. Relationship between biomarker activity and developmental endpoints in *Chironomus riparius* Meigen exposed to an organophosphate insecticide. *Ecotoxicology and Environmental Safety* 53: 361-369.

Cranston, P.S. 1995. *The Chironomidae–The Biology and Ecology of Non-bitting Midges*. In P. Armitage, P.S. Cranston and L.C.V. Pinder (Eds.), Chapman and hall, Londres.

Depledge, M.H. 1998. The ecotoxicological significance of genotoxicity in marine invertebrates. *Mutation Research* 399: 109-122.

Depledge, M.H. and Fossi, M.C. 1994. The role of biomarkers in environmental assessment (2). Invertebrates. *Ecotoxicology* 3: 161-172.

Depledge, M.H. 1994. The rational basis for the use of biomarkers as ecotoxicological tools. In M.C. Fossi and C. Leonzio (Eds.), *Nondestructive biomarkers in vertebrates* (pp. 261-285). Lewis Publishers, Boca Raton.

Depledge, M.H., Amaral-Mendes, J.J., Daniel B., Halbroo, R.S., Kloepper-Sams, P., Moore, M.N. and Peakall, D.B. 1993. The conceptual basis of the biomarker approach. In D.B. Peakall and L.R. Shugart (Eds.), *Biomarkers. Research and Application in the Assessment of Environmental Health*. NATO Advanced Science Institutes Series *68*, 15-29. Springer Verlag, Berlin.

Derr, S.K. and Zabik, M.J. 1972. Biologically active compounds in aquatic environment: the effect of DDE on the egg viability of *Chironomus tentans*. *Bulletin of Environmental contamination and Toxicology* 7: 366-368.

Detra, R.L. and Collins, W.J. 1991. The relationships of parathion concentration, exposure time, cholinesterase inhibition and symptoms of toxicity in midge larvae (*Chironomus*: Diptera). *Environmental Toxicology and Chemistry* 10: 1089-1095.

Dickerson, R.L., Hooper, M.J., Gard, N.W., Cobb, G.P. and Kendall, R.J. 1994. Toxicological foundations of ecological risk assessment: biomarker development and interpretation based on laboratory and wildlife species. *Environmental Health Perspectives* 102(suppl.): 65-69.

Engel, D.W. and Vaughan, D.S. 1996. Biomarkers, natural variability and risk assessment: Can they co-exist? *Human and Ecological Risk Assessment* 2: 257-262.

Estenik, J.F. and Collins, W.J. 1979. *In vivo* and *in vitro* studies of mixed-function oxidase in an aquatic insect, *Chironomus riparius*. *American Chemistry and Society* 99: 349-370.

Fisher, T., Crane, M. and Callaghan, A. 2003. Induction of cytochrome P-450 activity in individual *Chironomus riparius* Meigen Larvae exposed to xenobiotics. *Ecotoxicology and Environmental Safety* 54: 1-6.

Forbes, V.E. and Forbes, T.L. 1994. *Ecotoxicology in Theory and Practice*. Chapman and Hall, London.

Fossi, M.C., Casini, S., Savelli, C., Corbelli, C., Franchi, E., Mattei, N., Sanchez-Hernadez, J.C., Corsi, I., Bamber, S. and Depledge, M.H. 2000. Biomarker responses at different levels of biological organization in crabs (*Carcinus aestuarii*) experimentally exposed to benzo(a)pyrene. *Chemosphere* 40: 861-874.

Guecheva, T.N., Erddtmann, B., Benfato, M.S. and Henriques, J.A.P. 2003. Stress protein and catalase activity in freshwater planarian Dugesia (Girardia) schubarti exposed to cooper. *Ecotoxicology and Environmental Safety.* in press.

Guecheva, T.N., Henriques, J.A.P. and Erddtmann, B. 2001. Genotoxic effects of cooper sulphate in freshwater planarian in vivo, studied with the single-cell gel test (Comet assay). *Mutation Research* 497: 19-27.

Hudson, L.A. and Ciborowski, J.H. 1996. Teratogenic and genotoxic response of larval *Chironomus salinarius* group (Diptera: Chironomidae) to contaminated sediment. *Environmental Chemistry and Toxicology* 15: 1375-1381.

Hwang, H., Fisher, S.W. and Landrum, P.F. 2001. Identifying body residue of HCBP associated with 10-d mortality and partial life cycle effects in the midge, *Chironomus riparius*. *Aquatic Toxicology* 52: 251-267.

Hyne, R.V. and Maher, W.A. 2003. Invertebrate biomarker: links to toxicosis that predict population decline. *Ecotoxicology* and *Environmental Safety* 54: 366-374.

Ingersoll, C. and Nelson, M.K. 1990. Testing sediment toxicity with *Hyalella azteca* (amphipod) and *Chironomus riparius* (Diptera). In W. Landis, W. Van der Schalie (Eds.), *Aquatic Toxicology and Risk Assessment* (pp. 93-110). American Society of Testing and Materials, Philadelphia.

James, M.O. 1989. Biotransformation and disposition of PAHs in aquatic invertebrates. In U. Varanasi (Ed.), *Metaboilsm of Polycyclic Aromatic Hydrocarbons in the Aquatic Environment.* CRC Press, Boca Raton, FL.

Karnak, R.E. and Collins, W.J. 1974. The susceptibility to selected insecticides and acetylcholinesterase activity in a laboratory colony of midge larvae, *Chironomus tentans* (Diptera:*Chironomidae*). *Bulletin of Environmental contamination and Toxicology* 12: 62-69.

Karouna-Renier, N.K. and Zehr, J.P. 1999. Ecological implications of molecular biomarkers: assaying sub-lethal stress in the midge *Chironomus tentans* using heat shock protein 70 (HSP-70) expression. *Hydrobiologia* 401: 255-264.

Kendall, R.J., Anderson, T.A., Baker, R.J., Bens, C.M., Carr, J.A., Chiodo, L.A., Cobb, G.P., Dickerson, R.L., Dixon, K.R., Frame, L.T., Hooper, M.J., Martin, C.F., McMurry, S.T., Patino, R, Smith, E.E.

and Theodorakis, C.W. 2001. Ecotoxicology. In C.D. Klassen (Ed.), *Casarett and Doull`s Toxicology : The Basic Science of Poison* (pp. 1013-1045). 6th ed. McGRAW-Hill, New York.

Kosalwat, P. and Knight, A.W. 1987. Chronic toxicity of copper to a partial life cycle of the midge, *Chironomus decorus. Archive of Environmental contamination and Toxicology* 16: 283-290.

Lagadic, L., Caquet ,Th. and Ramade, F. 1994. The role of biomarkers in environmental assessment (5). Invertebrate populations and communities. *Ecotoxicology* 3: 193-208.

Lagadic, L., Caquet, Th., Amiard, J.C. and Ramade, F. 2000. Use of Biomarkers in Monitoring Environmental Health. Balkema, Rotterdam, The Nethrelands and Science Publishers, Inc., Enfield.

Landrum, P.F. and Robbins, J.A. 1990. Bioavailability of sediment-associated contaminants to benthic invertebrate. In R. Baudo, J.P. Giesy and H. Muntau (Eds.), *Sediments: chemistry and toxicity of in-place pollutants* (pp. 237-263). Lewis Publishers, Ann Arbor, MI.

Lindegaard, C. 1995. Classification of water-bodies and pollution. In P. Armitage, P.S. Cranston and L.C.V. Pinder (Eds.), *The Chironomidae. The biology and ecology of non-biting midges* (pp. 385-404), Chapman and Hall, New York.

Livingstone, D.R. 1991. Organic xenobiotic metabolism in marine invertebrates. *Advanced Comparative Environmental Physiology* 7: 45-185

Mattingly, K.S., Beaty, B.J., Mackie, R.S., McGaw, M., Carson, J.O. and Rayms-Keller, A. 2001. Molecular cloning and characterization of a metal responsive Chironomus tentant alpha-tublin cDNA. *Aquatic Toxicology* 54: 249-260.

Mayer, F.L., Versteeg, D.J., McKee, M.J., Folmar L.C., Graney, R.L., McCune, D.C. and Rattner B.A. 1992. Physiological and nonspecific biomarkers. In R.J. Huggette, R.A. Kimerle, P.M Mehrle Jr. and H.L. Bergman (Eds.), *Biomarkers*: *Biochemical, Physiological and Histological Markers of Anthropogenic Stress* (pp. 5-85). Lewis, Boca Raton, FL

McCarty, L.S. and Munkittrick, K.R. 1996. Environmental biomarkers in environmetal aquatic toxicology: friction, fantasy, or functional? *Human and Ecological Risk Assessment* 2: 268-274.

Meregalli, G., Bettinetti, R., Pluymers, L., Vermeulen, A. C., Rossaro, B. and Ollevier, F. 2002. Mouthpart Deformities and Nucleolus Activity in Field-Collected Chironomus riparius Larvae. *Archive of Environmental Contamination and Toxicology* 42: 405-409.

Michailova, P., Ilkova, J. and White, K.N. 2003. functional and structural rearrangements of salivary gland polytene chromosomes of *Chironomus riparius* Mg. (Diptera, Chironomidae) in response to freshly neutralized aluminium. *Environmental Pollution* 123: 193-207.

Michailova, P., Petrova, N., Sella, G., Ramella, L and Bovero, S. 1998. Structural-functional rearrangements in chromosome G in *Chironomus riparius* (Diptera, Chironomidae) collected from a heavy metal-polluted areas near Turin, Italy. *Environmental Pollution* 103: 127-134.

NAS/NRC (National Academy of Science / National Research Council). 1989. *Biologic markers in reproductive toxicology*. National Academy of Press, Washington DC.

Newman, M.C. and Unger, M.A. 2003. *Fundamentals of Ecotoxicology.* 2nd ed. CRC Press LLC, Boca Raton.

Newman, M.C. and Jagoe, C.H. 1996. *Ecotoxicology: A Hierachical Treatment*. CRC Press, New York.

NRC (National Research Council). 1987. Committee on Biological Makers. *Environmental Health and Perspectives* 74: 3-9.

Olsen, T., Ellerbeck, L., Fisher, T., Callaghan, A. and Crane, M. 2001. Variability in acetylcholinesterase and glutathion S-transferase activities in *Chironomus riparius* Meigen deployed in situ at uncontaminated field sites. *Environonmental Toxicology and Chemistry* 24: 1725-1732.

Osmulski, P.A. and Leyko, W. 1986. Structure, function and physiological role of *Chironomus* haemoglobin, *Comparative Biochemistry and Physiology B*. 85: 701-722.

Palawski, D.U., Hunn, J.B., Cheter, D.N. and Wiedmeyer, R.H. 1989. Interactive effects of acidity and aluminium exposure on the life cycle of the midge *Chironomus riparius* (Diptera). *Journal of Freshwater Ecology* 5: 155-162.

Pascoe, D., Williams, K.A. and Green, D.W.J. 1989. Chronic toxicity of cadmium to *Chironomus riparius* Meigen - effects upon larval development and adult emergence. *Hydrobiologia* 175: 109-115.

Peakall, D.B. 1994. The role of biomarkers in environmental assessment (1) Introduction. *Ecotoxicology* 3: 157-160.

Peakall, D.B. and Shugart, L.R. 1993. *Biomarkers: Research and Application in the Assessment of Environmetal Health*. Springer-Verlag, Berlin.

Pinder, L.C.V. 1986. Biology of freshwater Chironomidae. *Annual Review of Entomology* 31: 1-23.

Risso-de Faverney, C., Devaux, A., Lafaurie, M., Girard, J. P. and Rahmani, R. 2001. Toxic Effect of Wastewaters Collected at Upstream and Downstream Sites of a Purification Station in Culutures of Rainbow Trout Hepatocytes. *Archives of Environmental Contamination and Toxicology* 41: 129-141.

Segner, H., Caroll, K., Fenske M., Janssen, C.R., Maack, G., Pascoe, D., Schäfers, C., Vandenbergh, G. F., Watt, M. and Wenzel, A. 2003. Identification of endocrine-disrupting effects in aquatic vertegrates and invertebrates: report from the European IDEA project. *Ecotoxicology and Environmental Safety* 54: 302-314.

Synder, M.J. and Mulder, E.P. 2001. Environmental endocrine disruption in decapod crustacean larvae: hormone titers, cytochrome P450, and stress protein responses to heptachlor exposure. *Aquatic Toxicology* 55: 177-190.

Taylor, E.J., Blockwell, S.J., Maund, S.J. and Pasco, D. 1993). Effects of lindane on the life-cycle of a freshwater macroinvertebrate *Chironomus riparius* Meigen (Insecta: Diptera). *Archive of Environmental contamination and Toxicology* 24: 145-150.

Vermeulen, A.C. 1995. Elaborating chironomid deformities as bioindicators of toxic sediment stress: the potential application of mixture toxicity concepts. *Ann. Zool. Fenn*. 32: 265-285

Watts, M.M., Pascoe, D. and Carroll, K. 2001. Chronic exposure to 17α-ethinylestradiol and bisphenol A-effects on development and reproduction in the freshwater invertebrate *Chironomus riparius* (Diptera: Chironomidae). *Aquatic Toxicology* 55: 113-124.

Weber, R.E. and Vinogradov, S.N. 2001. Non-vertebrate hemoglobins: Function and molecular adaptation. *Physiological Review* 81: 569-628.

Weber, R.E. 1980. Functions of invertebrate Hemoglobins with special reference to adaptations to environmental hypoxia. *Am. Zool*. 20: 79-101.

Wheelock C.E., Baumgartner T.A., Newman J.W., Wolfe M.F. and Tjeerdema R.S. 2002. Effect of nutritional state on Hsp60 levels in the rotifer *Brachionus plicatillis* following toxicants exposure. *Aquatic Toxicology* 61: 89-93.

Williams, K.A., Green, D.W.J., Pasco, D. and Gower, D.E. 1987. Effect of cadmium on oviposition and egg viability in *Chironomus riparius* (Diptera:Chironomidae). *Bulletin of Environmental contamination and Toxicology* 38: 86-90.

Wilson, J.T., Pascoe, P.L., Parry, J.M. and Dixon, D.R. 1998. Evaluation of the comet assay as a method for the detection of DNA damage in the cells of marine invertebrate, *Mytilus edulis* L. (Mollusca: Pelecypoda). *Mutation Research* 399: 87-95.

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CHAPTER 14

BIOMASS AND NUTRIENT CYCLING OF NATURAL OAK FORESTS IN KOREA

1. INTRODUCTION

The forest area in Korea occupies 6.3 million ha, about 65% of the total land area as of 2000. The forest can be classified into three groups: coniferous (2.7 million ha), deciduous (1.7 million ha), and mixed (1.9 million ha) forests, and most of the dominant species of deciduous and mixed forests are oak (*Quercus*) species (Korea Forest Service 2001). Oak species occupy a wide variety of ecological conditions and zones ranging from lowland warm temperate to upper montane conditions, and have been intensively utilized for many different purposes in the country. There is no doubt that oak species play the most important role in ecological aspects and production of wood and by-products of the Korean forests.

Six deciduous oak species (*Q. aliena, Q. acutissima, Q. dentata, Q. mongolica, Q. serrata*, and *Q. variabilis*), few varieties and hybrids are commonly found throughout the country and five evergreen oak species (*Q. acuta, Q. gilva, Q. glauca, Q. myrsinaefolia,* and *Q. salicina*) are scattered along the southern coasts and islands. Many of the previous studies investigated biomass and production, and relatively few studies examined nutrient distribution and cycling of the oak forests. However, most of these studies focused on the deciduous oak forests. The primary object of the current study is to provide an overview of biological productivity and nutrient cycling for natural oak forests in Korea.

We collect and compare data sets on biomass and nutrient cycling for the species from the literature, and also include our own data from the on-going research project ("Effects of the changes in local environments on the nutrient cycling of the natural oak stands in Korea" supported by the Korea Science and Engineering Foundation-R01-2000-000-00206-0). As nitrogen (N) and phosphorus (P) are the most common nutrient limiting production in temperate forests, our review focuses on N and P as well as organic matter.

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2. BIOMASS AND PRODUCTION

2.1. Aboveground biomass and production

In Korea, studies on biomass and production of forests using the dimension analysis technique has been published since 1969. The studies are meaningful in investigating biomass distribution among tree components, productivity and ecological information of forests. Currently researches on estimating national-scaled forest biomass by major forest types are being carried out to re-estimate forest resources related to whole tree utilization and the carbon stock of forests. Natural forests of *Q. variabilis* and *Q. mongolica*. have been mainly focused on in the study of biomass and production of oak forest in Korea. However, the number of stands examined is not sufficiently large and most studies are limited to aboveground biomass and production of the tree layer excluding roots and undergrowth. This makes it difficult to derive comprehensive information on biomass and production of oak forests from existing data. Thus, the contents of this synthesis are inevitably of more or less tentative nature, and this summary may be of use as a starting point for more advanced studies.

2.1.1. Overstory vegetation

Although five evergreen oak species are found in southern Korea, they usually occur in a small area and their economic values seem to be low. Consequently, no data on biomass and production for these species are available in the literature. Also there is no published data on biomass and production for *Q. aliena*, one of the six major deciduous oak species in Korea. We present a summary table of aboveground biomass for other deciduous oak species (Table 1). Aboveground biomass (ton/ha) ranges from 31.3 for 20-year-old *Q. variabilis* to 438.0 for 50-year-old *Q. mongolica*. However, except for the exceptionally high density stand in Kangwon area (438.0 ton/ha) the values are similar to those reported for other deciduous oak species (40-240 ton/ha) in temperature regions (Kimmins et al. 1985). Aboveground biomass seems significantly different among native oak species. Park et al. (1996) compare biomass and production of four oak species with similar ages (Table 2). Those stands are regenerated in a similar environment. Although *Q. acutissima* has lowest stand density compared to other three oak species, its DBH and height are highest.

They speculate that the high net assimilation ratio (total net production / leaf biomass) of *Q. acutissima* results in the greatest aboveground biomass. In a separate study, Park et al. (2003) also compare biomass between *Q. mongolica* and *Q. variabilis*. However, *Q. mongolica* having lower net assimilation ratio shows greater total biomass (aboveground plus belowground) than *Q. variabilis*. Further studies with large number of replicates are needed to investigate the differences in biomass among oak species. In general, aboveground biomass increases with stand age, and the linear correlation is statistically significant (Figure 1). However, it is not clear if the pattern continues beyond the stand age of about 50-60 year. Currently most of oak forests are 20-50 years-old secondary forests. The proportion of tree component

(stem, branch and leaf) to total aboveground biomass may differ among oak species. However, there is no enough data to analyze the differences in this study.

Table 1. Aboveground biomass (ton/ha) of oak species by tree compartment in Korea

Location	*Age*	*Stem*	*Branch*	*Leaf*	*Total*	*Reference*
			Mixed *Quercus* spp.			
Kyunggi	33	50.0	8.4	3.2	61.6	Lee and Kim 1997
			Q. acutissima			
Kyunggi	13	52.2	12.0	5.3	69.5	Chae and Kim 1977
Kyunggi	38	94.8	26.0	1.9	122.7	Park *et al.* 1996
Chunnam	26	99.8	31.6	8.7	140.1	Park and Moon 1994
			Q. dentata			
Kyunggi	38	22.2	14.5	1.9	38.6	Park *et al.* 1996
			Q. mongolica			
Kangwon	-	42.1	4.9	1.1	48.1	Kim and Yoon 1972
Kangwon	36	62.7	17.3	3.9	83.9	Lee and Park 1986
Kangwon	50	345.0	88.2	4.8	438.0	Park *et al.* 2003
Kyunggi	22	78.3	28.9	5.4	112.6	Lee and Park 1987
Kyunggi	34	40.7	28.8	2.7	72.2	Park *et al.* 1996
Chungbuk	67	91.1	33.2	5.1	129.4	Song and Lee 1996
Chunnam	36	70.4	23.1	4.3	97.8	Park and Moon 1994
Chunnam	37	36.5	11.4	2.0	49.9	Kim and Park 1986
			Q. serrata			
Kyunggi	22	40.6	13.8	4.0	58.4	Kim 1995
Kyungbuk	37	63.1	23.8	1.4	88.3	Park and Lee 2002
Chunbuk	25	31.2	9.3	1.5	42.0	Park and Lee 2002
Chunnam	29	68.8	23.9	4.5	97.2	Park and Moon 1994
Chunnam	34	40.7	13.7	1.6	56.0	Park and Lee 2002
			Q. variabilis			
Kangwon	49	227.7	49.4	2.8	279.9	Park *et al.* 2003
Kangwon	54	58.8	10.5	2.1	71.4	Park and Lee 2001
Kyunggi	22	113.6	14.6	3.2	131.4	Son *et al.* 1993
Kyunggi	32	72.3	12.5	2.2	87.0	Park *et al.* 1996
Chungbuk	62	100.8	27.2	3.8	131.8	Song and Lee 1996
Kyungbuk	45	172.9	32.2	2.5	207.6	Park and Lee 2001
Kyungnam	19	29.4	6.6	2.5	38.5	Kim and Jeong 1985
Kyungnam	20	45.0	6.2	2.8	54.0	Kim and Jeong 1985
Chunnam	20	22.0	7.3	2.0	31.3	Choi and Park 1993
Chunnam	28	95.3	31.3	8.3	134.9	Park and Moon 1994
Chungnam	41	76.6	12.5	2.1	91.2	Park and Lee 2001

Table 2. Comparison of aboveground biomass (ton/ha) and net production (ton/ha/yr) among four oak species grown in similar environments in Korea (after Park et al. 1996). Net assimilation ratio = total net production / leaf biomass.

	Q. variabilis	*Q. acutissima*	*Q. dentata*	*Q. mongolica*
Stand age (yr)	32	38	38	34
Mean DBH (cm)	14.9	21.3	11.7	15.0
Mean height (m)	14.4	15.3	9.7	11.6
Density (trees/ha)	1129	437	789	705
Basal area (m^2/ha)	20.8	16.4	11.8	18.6
Biomass (%)				
Stem	72.32 (83)	94.83 (77)	22.20 (58)	40.65 (56)
Branch	12.48 (14)	26.05 (21)	14.45 (37)	28.82 (40)
Leaf	2.23 (3)	1.85 (2)	1.91 (5)	2.67 (4)
Total	87.03 (100)	122.73 (100)	38.56 (100)	72.14 (100)
Production (%)				
Stem	3.43 (53)	3.17 (52)	0.93 (26)	2.66 (36)
Branch	0.81 (13)	1.04 (17)	0.68 (19)	2.16 (29)
Leaf	2.23 (34)	1.85 (31)	1.91 (54)	2.67 (35)
Total	6.47 (100)	6.06 (100)	3.52 (100)	7.49 (100)
Assimilation ratio	2.898	3.275	1.840	2.888

The average contribution of stem, branch and leaf to total aboveground biomass over the different oak species is 75%, 21% and 4%, respectively. The contribution of leaf to total aboveground biomass continuously decreases with stand age, from 7.6% for a 13 years-old stand to 3.9% for a 67 years-old stand for oak species ($R=0.61$, $p<0.0001$). In contrast, there are no significant correlations between stand age and the contribution of stem or branch to total aboveground biomass ($p>0.05$) (Figure 2). Aboveground net production (ton/ha/yr) ranges from 3.5 for a 38 years-old *Q. dentata* stand to 20.8 for a 28 years-old *Q. variabilis* stand (Table 3). Approximately 50% of the net production are allocated to stem. Net production differs among oak species, and also changes with stand age. However, there is no correlation between net production and stand age. Aboveground net production increases with total aboveground biomass for oak species, and the relationship is significant ($p<0.001$) (Figure 3).

2.1.2. Understory Vegetation

In natural oak forests, quite a few understory shrub and herbaceous species are found. However, there are limited data on understory species composition, biomass, and production for the forests.

It is reported that common understory woody vegetation in oak forests is *Acer pseudo-sieboldianum, Lespedeza bicolar, L. cyrtobotrya, Actinidia arguta, Stephanandra incisa, Lindera obtusiloba, L. erythrocarpa, Corylus heterophylla,*

Prunus mandshurica var. *glabra, P. sargentii, Betula davurica, Rosa multiflora, Rhus trichocarpa, Ulmus davidiana* var. *japonica,* and *Styrax japonica* while understory herbaceous vegetation is *Sophora angustifolia, Miscanthus sinensis, Syneilesis palmata, Atractylodes japonica, Carex siderosticta,* and *Pteridium auilium* var. *latiusculum* (Kim unpublished data; Kwak and Kim 1992, Mun and Joo 1994, Mun *et al.* 1977).

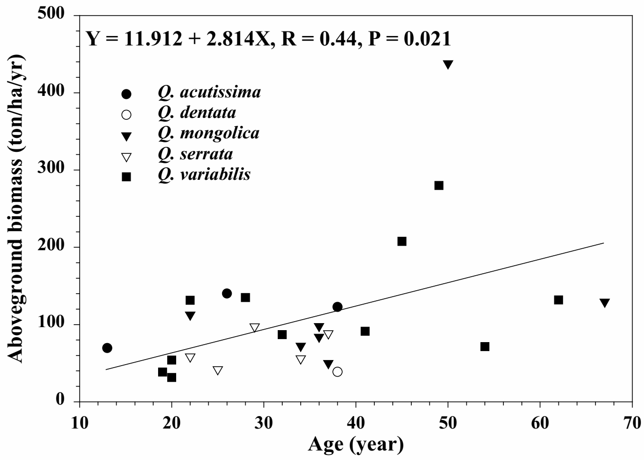
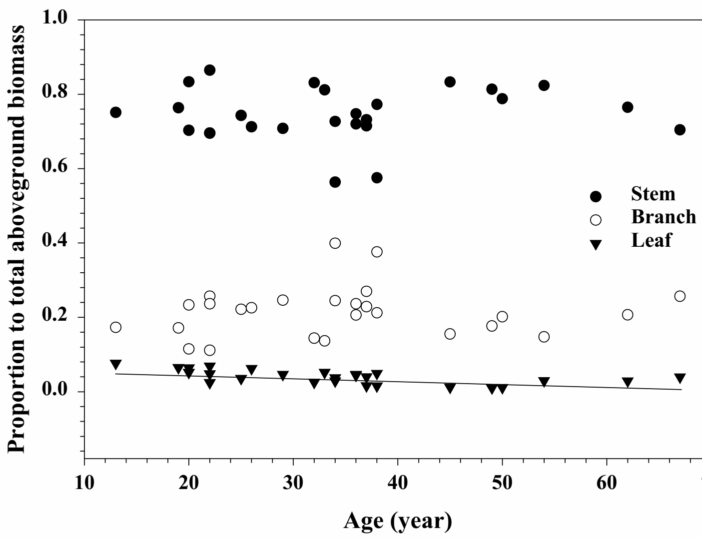


Figure 1. Relationship between stand age and aboveground biomass for deciduous oak species in Korea.

Species in understory vegetation differs depending on the dominant overstory oak species. In general, more understory species are found under *Q. variabilis* than under *Q. mongolica* within an area, and light condition and soil moisture seem to influence the difference (Kim unpublished data). Proportion of understory (woody plus herbaceous) biomass to total aboveground (overstory plus understory) biomass ranges from 0.9% to 22.2% (Table 4). There is a negative correlation between the proportion and the total aboveground biomass (Figure not shown, R = -0.63, P = 0.07). Light interception by overstory vegetation seems to influence the production of understory vegetation.

2.2. Belowground Biomass

Few studies report belowground biomass for oak forests in Korea, however, some of them indirectly estimate belowground portion using the ratio of aboveground biomass (Chae and Kim 1977, Song and Lee 1996). In the literature, roots biomass



(Figure 2. Changes in proportion of stem, branch, and leaf to total aboveground biomass with stand age for oak species in Korea.

Table 3. Aboveground net production (ton/ha/yr) of oak species in Korea

Location	*Age*	*Stem*	*Branch*	*Leaf*	*Total*	*Reference*
			Q. acutissima			
Kyunggi	13	7.7	2.3	5.3	15.3	Chae and Kim 1977
Kyunggi	38	3.2	1.0	1.9	6.1	Park *et al.* 1996
Chunnam	26	10.4	3.4	8.7	22.5	Park and Moon 1994
			Q. dentata			
Kyunggi	38	0.9	0.7	1.9	3.5	Park *et al.* 1996
			Q. mongolica			
Kangwon	-	7.6	0.7	0.4	8.7	Kim and Yoon 1972
Kangwon	36	3.6	5.1	3.9	12.6	Lee and Park 1986
Kangwon	50	8.9	4.1	4.8	17.8	Park *et al.* 2003
Kyunggi	22	5.9	2.7	5.4	14.0	Lee and Park 1987
Kyunggi	34	2.7	2.2	2.7	7.6	Park *et al.* 1996
Chungbuk	67	2.3	2.6	5.1	10.0	Song and Lee 1996
Chunnam	36	5.3	1.5	4.3	11.1	Park and Moon 1994
Chunnam	37	1.3	0.5	2.1	3.9	Kim and Park 1986

			Q. serrata			
Kyungbuk	37	3.9	2.3	1.4	7.6	Park and Lee 2002
Chunbuk	25	2.2	2.8	1.5	6.5	Park and Lee 2002
Chunnam	29	6.4	1.9	4.6	12.9	Park and Moon 1994
Chunnam	34	2.3	2.3	1.6	6.2	Park and Lee 2002
			Q. variabilis			
Kangwon	49	9.0	2.5	2.8	14.3	Park *et al.* 2003
Kangwon	54	3.1	1.2	2.1	6.4	Park and Lee 2001
Kyunggi	32	3.4	0.8	2.2	6.4	Park *et al.* 1996
Chungbuk	62	2.7	2.1	3.8	8.6	Song and Lee 1996
Kyungbuk	45	5.3	3.7	2.5	11.5	Park and Lee 2001
Kyungnam	19	3.7	0.5	2.5	6.7	Kim and Jeong 1985
Kyungnam	20	5.9	0.3	2.8	9.0	Kim and Jeong 1985
Chunnam	20	1.7	0.6	2.0	4.3	Choi and Park 1993
Chunnam	28	9.5	3.0	8.3	20.8	Park and Moon 1994
Chungnam	41	3.2	2.5	2.1	7.8	Park and Lee 2001

Table 4. Aboveground (overstory and understory vegetation), roots, and stand total biomass (ton/ha) of oak species in Korea

Location	*Age*	*Aboveground*		*Roots*	*Total*	*Reference*
		Over story	*Under story*			
			Q. acutissima			
Kyunggi	13	69.4	-	17.4	86.8	Chae and Kim 1977
Chunnam	26	140.1	-	23.9	164.0	Park and Moon 1994
			Q. mongolica			
Kangwon	50	438.0	3.8	58.5	500.3	Park *et al.* 2003
Kyunggi	22	112.6	8.1	35.4	156.1	Lee and Park 1987
Chungbuk	67	130.6	15.8	-	-	Song and Lee 1996
Chunnam	36	97.8	-	21.0	118.8	Park and Moon 1994
Chunnam	37	49.9	5.4	-	-	Kim and Park 1986
			Q. serrata			
Chunnam	29	97.2	-	18.1	115.3	Park and Moon 1994
			Q. variabilis			
Kangwon	49	279.9	2.8	38.4	321.1	Park *et al.* 2003
Kyunggi	34	119.5	3.6	15.7	138.8	Park, unpublished data
Chungbuk	62	137.4	25.1	-	-	Song and Lee 1996
Kyungnam	19	38.5	11.0	-	-	Kim and Jeong 1985
Kyungnam	20	53.9	5.3	-	-	Kim and Jeong 1985
Chunnam	28	134.9	-	24.0	158.9	Park and Moon 1994

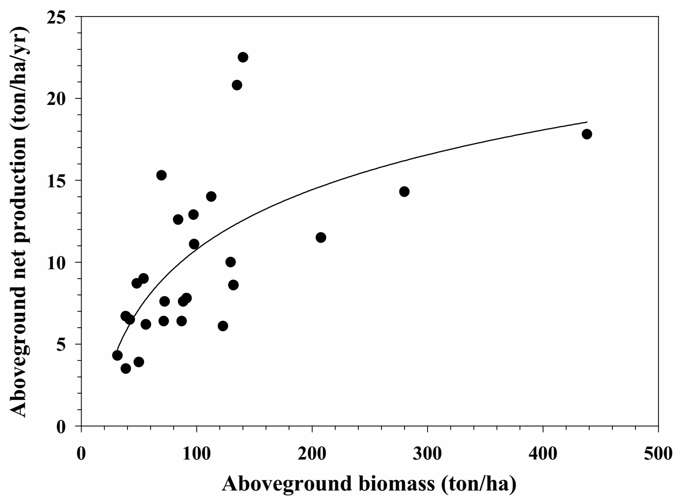


Figure 3. Relationship between aboveground biomass and aboveground net production for oak species in Korea.

ton/ha) varies from 15.7 for a 34 years-old *Q. variabilis* stand to 58.5 for a 50 years-old *Q. mongolica* stand, respectively. The proportion of roots biomass to total vegetation biomass is 11-23% (Table 4). Currently, no fine root data (biomass, production and nutrient) is available for the species.

3. NUTRIENT DISTRIBUTION

3.1. Nutrient Contents in Vegetation

Nitrogen and P contents (kg/ha) in vegetation (total above- and belowground components) range from 470 and 27 to 1650 and 365 (Table 5). In general, N and P contents are highest in aboveground overstory vegetation (stem, branch and leaf) followed by roots and understory vegetation. However, N content in roots (483 kg/ha of total 737 kg/ha) is exceptionally highest for a 22 years-old *Q. mongolica* stand (Lee and Park 1987). The proportions of N and P contents (%) in aboveground overstory vegetation, aboveground understory vegetation and roots to total vegetation are approximately 70 and 75, 10 and 5, and 20 and 20, respectively (Table 5). Nitrogen and P contents in aboveground vegetation increase with stand age, and the linear correlations are significant (for nitrogen: R = 0.90, P = 0.01, for phosphorus: R = 0.76, P = 0.08) (Figure 4). In aboveground overstory vegetation,

most of N and P contents are found in stem. Nitrogen and P concentrations for oak species are highest in leaf followed by branch and stem (Kwak and Kim 1992, Lee and Park 1987, Mun *et al.* 1977, Park unpublished data). Although leaf averages 4% of the total aboveground overstory biomass (Table 1), it contains 8-32% and 1-36% of the total aboveground overstory N and P contents, respectively.

Table 5. Nitrogen and P contents (kg/ha) in vegetation for oak species in Korea (after Kwak and Kim 1992, Lee and Park 1987, Lee et al. 1987, Mun et al. 1977, Park unpublished data).

		Q. variabilis		*Q. acutissima*		*Q. mongolica*	
		N	*P*	*N*	*P*	*N*	*P*
Location		Kangwon		Kyunggi		Kangwon	
Stand age (yr)		44		13		50	
Overstory	Stem	502.5	59.7	127	8.5	714.7	185.7
	Branch	230.8	17.0	40	3.0	503.3	130.0
	Leaf	60.8	2.5	41	6.5	104.9	4.0
Understory		47.8	6.2	66	3.5	29.5	4.9
Roots		213.8	26.4	71.5	7.5	300.3	40.7
Total		1055.7	111.8	345.5	29.0	1652.7	365.3
Location		Kyunggi		Kyunggi		Kyunggi	
Stand age (yr)		34		29		22	
Overstory	Stem	244.8	23.3	339.7	63.7	87.7	4.7
	Branch	86.9	5.3	196.4	18.7	81.2	8.1
	Leaf	47.8	1.2	53.4	3.5	76.8	2.1
Understory		21.2	1.7	-	-	8.1	1.0
Roots		70.4	5.7	483.6	54.6	483.2	10.6
Total		471.1	37.1	1073.1	140.5	737.0	26.5

3.2. Nutrient Contents among Ecosystem Components

Total ecosystem N and P contents (kg/ha) of oak forests vary from 3100 and 75 to 20750 and 880 depending on species, age, and location (Kwak and Kim 1992, Lee *et al.* 1987, Mun *et al.* 1977). When a forest ecosystem is divided into three components (vegetation, forest floor, and soil), soils seem to be the largest nutrient pool. In a 22 years-old *Q. serrata* stand, ecosystem (aboveground vegetation + forest floor + 20cm depth soil) N and P contents (kg/ha) are 4846 and 57, and 93% of N and 59% of P are distributed in soils (Kim, 1995). Lee and Park (1987) also conclude that forest soil (0-30cm depth) is the largest N (75% of total 3133 kg/ha) and P (70% of total 90 kg/ha) pools for a 22 years-old *Q. mongolica* stand. Soil nutrient contents generally decrease with soil depth, however, very few studies measure the differences. Son (unpublished data) reports N contents (kg/ha) of 1550 for 0-10cm, 1439 for 10-20cm, and 373 for >20cm soil depth in a 50 years-old *Q. mongolica* stand, and 706 for 0-10cm, 667 for 10-20cm and 289 for >20cm soil depth in a 49 years-old *Q. variabilis* stand, respectively.

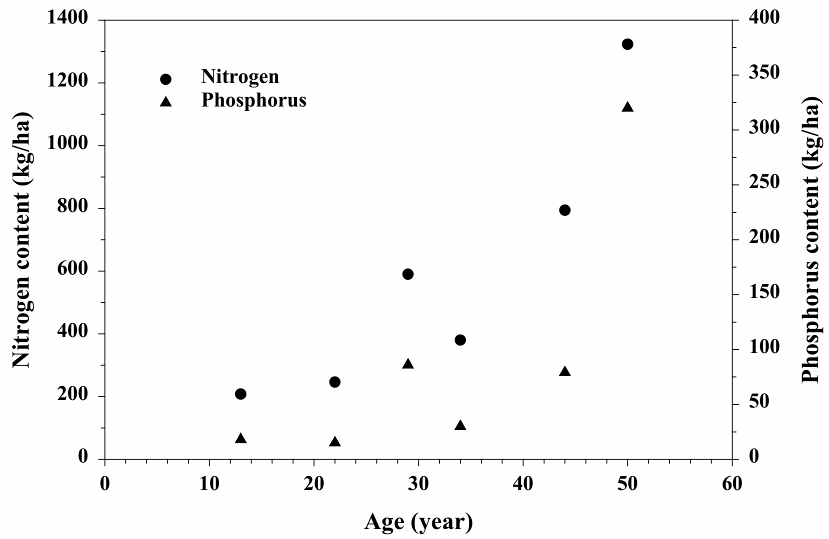


Figure 4. Changes in N and P contents (kg/ha) of aboveground overstory vegetation with stand age for oak species in Korea (after Kwak and Kim 1992, Lee and Park 1987, Lee et al. 1987, Mun et al. 1977; Park unpublished data).

4. NUTRIENT CYCLING

4.1. Nutrient Uptake, Retention and Return

Nutrient uptake, retention and return are calculated using the mass balance equation. Few researchers examine these indices of nutrient cycling for oak forests in Korea (Table 6). Nutrient uptake is the sum of nutrients incorporated into new tissues and biomass increment, and nutrient return is the sum of nutrients in annual litterfall. Nutrient retention is estimated by the difference between nutrient uptake and return. Nitrogen and P uptake (kg/ha/yr) range from 94 and 9 to 174 and 13, respectively.

Approximately 50% of N and P uptake are returned to soil, and the rest are retained in above- and belowground vegetation. Soil N mineralization rates seem to be close to N uptake for oak forests (see *Soil N Mineralization* section below).

Table 6. Nitrogen and P uptake, retention, and return (kg/ha/yr) for oak forests in Korea (after Kwak and Kim 1992, Lee et al. 1987, Mun et al. 1977).

Species	*Age (yr)*	*Nutrient*	*Uptake*	*Retention*	*Return*
Q. acutissima	13	N	131.0	44.0	87.0
		P	12.5	3.5	9.0
Q. acutissima	-	N	93.9	40.6	53.4
		P	8.8	5.3	3.5
Q. mongolica	40	N	174.2	117.0	57.2
		P	9.9	6.4	3.5

4.2. Litterfall Input and Decomposition

Litterfall production (kg/ha/yr) for oak species ranges from 2480 to 10770 for a *Q. acutissima* stand (Table 5). Except for the unusually high production of 10770 kg/ha/yr (Chang and Kwon 1987), total annual litterfall production in the region is within the range of 2300-7100 kg/ha/yr for deciduous oak species in temperate areas (Kimmins *et al.* 1985). As there are very limited litterfall production data long the latitudinal gradient, an inverse relationship between annual litterfall production and latitude is not observed in this study (Vogt *et al.* 1986). However, there is a negatively significant correlation between annual litterfall production and altitude in Korea (Figure 5). Temperature is considered as an influencing factor for litterfall production along the altitudinal gradient in a mountain (Chang and Kwon 1987). Nitrogen and P inputs (kg/ha/yr) via litterfall range from 20.4 and 0.2 to 164.2 and 9.2, respectively (Table 7). Means of litterfall N and P inputs (kg/ha/yr) are 53.8 and 3.7, and these values are similar to 39.5 and 4.2 reported for temperate deciduous forests (Vogt *et al.* 1986).

Climatic factors such as precipitation and air temperature appear to have a strong influence on decomposition rates of litter. Chang *et al.* (1987) report that there is a negatively significant correlation between the latitude and decay constant of litter for *Q. mongolica* ($Y = 0.568 - 0.0118X$, $R = -0.93$, $P<0.01$). Also they report a negative relationship between the altitude and decay constant of litter for the same species in Korea ($Y = 0.3800 - 0.000154X$, $R = -0.89$, $P<0.01$). However, air temperature is more important in litter decomposition than precipitation at high altitudes (Park and Lee 1981). Aspect significantly influences litter decomposition, and the decomposition rate is highest in east followed by south-east, north-west, north-east, north, south, and south-west aspects (Park and Kim 1985). There is a close relation between the decomposition rate and the number of fungi in the soil (Park and Kim 1985). Decay constants calculated following Olson (1963) for oak species range from 0.12 for *Q. mongolica* to 0.45 for *Q. acutissima* (Chang and Chung 1986, Chang and Kwon 1987, Yi, unpublished data). And mean residence time (the ratio of forest floor mass to mass of an annual litterfall) ranges from 1.49

year for *Q. mongolica* to 2.78 year for *Q. variabilis*, respectively, and the differences seem to be derived from soil moisture and litter quality (Yi, unpublished data).

4.3. Soil N Mineralization

We summarize soil N mineralization data of oak species (Table 8). All of these data are obtained using the on-site incubation method in central Korea. The approach involves placing undisturbed soil cores in plastic bags and burying them for 30-45 days. These incubations are repeated over an annual cycle, and annual estimates of net N mineralization can be calculated (Fisher and Binkley 2000). Annual net N mineralization (kg/ha/yr) ranges from 76 for *Q. variabilis* to 114 for *Q. acutissima*. These values are higher than those reported for coniferous species except for *Larix* species in the region (Mun 1991, Son and Lee 1997). It appears that *Q. mongolica* stands have higher net N mineralization rates compared to *Q. variabilis* stands within an area. Usually *Q. variabilis* occurs on relatively dry southern aspects while *Q. mongolica* on moist northern aspects in central Korea.

Table 7. Annual litterfall production (kg/ha/yr), and N and P inputs (kg/ha/yr) through litterfall for oak species in Korea

Location	*Age*	*Production*	*N*	*P*	*Reference*
		Q. acutissima			
Kangwon	-	6238	36.7	3.5	Chang and Kwon 1987
Kangwon	-	4430	37.3	4.4	Chang and Kwon 1987
Kangwon	-	2612	20.4	4.6	Chang and Kwon 1987
Kyunggi	13	6300	87	9.0	Mun *et al.* 1977
Chungnam	35	5671	61.0	0.6	Mun and Joo 1994
Chungbuk	-	10773	44.7	9.2	Chang and Kwon 1987
Chungbuk	-	4521	57.8	7.1	Chang and Kwon 1987
Chungbuk	-	2480	25.3	2.2	Chang and Kwon 1987
Chunbuk	-	6862	82.9	2.3	Chang and Chung 1986
Chunnam	55	5112	60.6	0.7	Chang and Han 1985
		Q. mongolica			
Kangwon	40	4269	57.2	3.5	Kwak and Kim 1992
Kangwon	50	4505	60	3	Yi, unpublished data
Chunbuk	-	3790	64.6	2.2	Chang and Chung 1986
Chunbuk	-	8761	164.2	5.0	Chang and Chung 1986
		Q. serrata			
Kyunggi	22	4696	32.4	3.2	Kim 1995
Kyunggi	27	3960	39.6	0.4	Park and Lee 1980
Chunnam	-	3383	80	4	Chang and Kim 1983
		Q. variabilis			
Kangwon	44	3820	48	2	Yi, unpublished data
Kangwon	49	3358	38	2.5	Yi, unpublished data

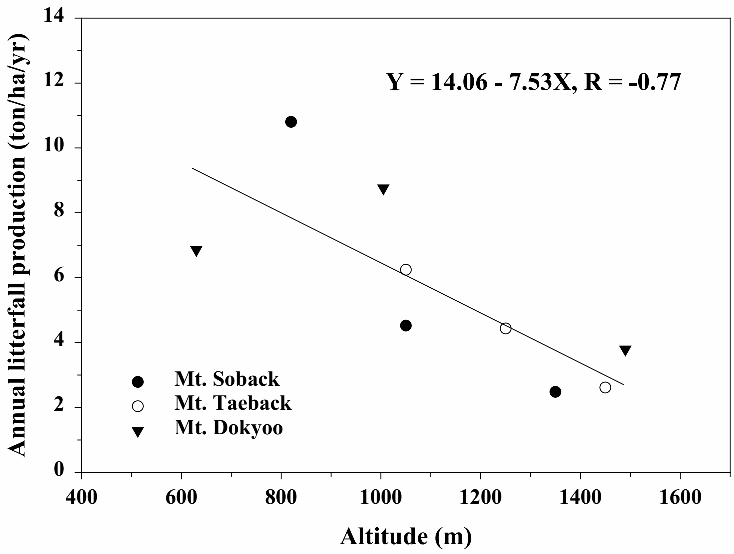


Figure 5. Relationship between annual litterfall production and altitude for deciduous oak species in Korea (after Chang and Chung 1986, Chang and Kwon 1987).

Consequently, mean annual soil moisture contents are significantly higher under *Q. mongolica* stands than under *Q. variabilis* stands (Lee, unpublished data). Soil moisture conditions might influence differences in N mineralization rates between two species. However, differences in litter quality might also influence N mineralization rates (Son and Lee 1997). Soil N availability measured using ion exchange resin bags is also much higher under *Q. mongolica* than under *Q. variabilis*. For example, annual total N (NH_4^+ + NO_3^-) availability for *Q. mongolica* and *Q. variabilis* in the Kangwon area is 30.6 and 17.3 mg N/bag, respectively (Son, unpublished data). Percent nitrification ranges from 66% to 82%. Nitrification ratios of oak species are significantly lower than those of coniferous species in the region (Son and Lee 1997, Son *et al.* 1995, Son *et al.* 1999).

4.4. Nutrient and Hydrologic Cycles

Kwak and Kim (1992) measure nutrient inputs through hydrologic cycles in a *Q. mongolica* stand. They report that N and P inputs (kg/ha/yr) to the ecosystem by precipitation are 10.3 and 0.1 while those to the soil by throughfall are 8.7 and 0.2, respectively.

Table 8. Annual net N mineralization (kg/ha/yr) and percent nitrification of oak forests in Korea

Species	*Age*	*Net N min.*	*Nitrifi-cation*	*Reference*
Q. acutissima	70	114	69	Kim 1998
Q. mongolica	50	113	79	Son, Unpublished data
Q. serrata	22	112	76	Son and Lee 1997
Q. variabilis	34	76	82	Son, Unpublished data
Q. variabilis	44	106	79	Son, Unpublished data
Q. variabilis	49	91	66	Son, Unpublished data
Mixed *Q. variabilis* and *Q. mongolica*	31	108	79	Son, Unpublished data
Mixed *Q. variabilis* and *Q. mongolica*	33	98	81	Son, Unpublished data

Nitrogen and P loss (kg/ha/yr) by surface runoff are 4.2 and 0.02. About 5% of annual N uptake are supplied either by precipitation or by throughfall in the study stand (Kwak and Kim 1992).

In a separate study, Jin (unpublished data) measures 7-12 kg/ha/yr of NO_3^- input by throughfall for *Q. mongolica* and *Q. variabilis* stands. Nitrogen in soil solution significantly decreases from surface to subsurface soils in the same stand. It appears that N uptake by roots in the subsurface soils results in decreased N contents in soil solution.

4.5. Soil CO_2 Evolution

Yi (unpublished data) compares soil CO_2 evolution between *Q. mongolica* and *Q. variabilis* stands. Total annual CO_2 evolution (ton/ha/yr) is 31.5-34.8 for *Q. variabilis* and 34.2 for *Q. mongolica*, respectively. Although mean annual soil moisture is higher under *Q. mongolica* than under *Q. variabilis*, there is no correlation between soil CO_2 evolution and soil moisture content. Soil temperature is the major influencing factor.

5. REFERENCES

Chae, M.I. and Kim, J.H. 1977. Comparison of biomass, productivity and productive structure between Korean alder and oak stands. *Korean Journal of Ecology* 1: 57-66.

Chang, N.K. and Chung, M.A. 1986. A study on the production and decomposition of litters along altitude of Mt. Dokyoo. *Korean Journal of Ecology* 9: 185-192.

Chang, N.K. and Han, S.E. 1985. A study on the production and decomposition of litters of evergreen broadleaved forests in Haenam and Koje-Do. *Korean Journal of Ecology* 8: 163-169.

Chang, N.K. and Kim, I.J. 1983. A study of the matter production and decomposition of *Quercus serrata* and *Carpinus laxiflora* forests at Piagol in Mt. Jiri. *Korean Journal of Ecology* 6: 198-207.

Chang, N.K. and Kwon, H.C. 1987. A study on the production and decomposition of litters related to altitude. *Korean Journal of Ecology* 10: 109-118.

Chang, N.K., Lee, S.K., Lee, B.S. and Kim, H.B. 1987. The decay map and turnover cycles of litters in Korea. *Korean Journal of Ecology* 10: 183-193.

Choi, Y.C. and Park, I.H. 1993. Biomass and net production of a natural *Quercus variabilis* forest and a *Populus alba x P. glandulosa* plantation at Mt. Mohu area in Chonnam. *Journal of Korean Forestry Society* 82: 188-194.

Fisher, R.F. and Binkley, D. 2000. *Ecology and Management of Forest Soils*. John Wiley and Sons, Inc. New York.

Kim, J.S. 1995. *Biomass and distribution of nitrogen and phosphorus for Pinus rigida, Larix leptolepis and Quercus serrata stands in Yangpyeong*. Korea University Ph.D. theses.

Kim, C.S. 1998. Nitrogen mineralization and nitrification in a mature *Quercus acutissima* stand in Kwangnung, Kyonggi Province. *Journal of Korean Forestry Society* 87: 20-26.

Kim, J.H. and Yoon, S.M. 1972. Studies on the productivity and the productive structure of the forests II. Comparison between the productivity of *Pinus densiflora* and of *Quercus mongolica* stands located near Choon-Chun City. *Korean Journal of Botany* 15: 71-78.

Kim, K.D. and Park, I.H. 1986. Aboveground biomass and production of a *Quercus mongolica* forest at a ridge in Mt. Baekun area. *Research Bulletin of Seoul National University Forests* 22: 1-9.

Kim, S.K. and Jeong, J.Y. 1985. A study on the production structure and biomass productivity of *Quercus variabilis* natural forest. *Journal of Korean Forestry Society* 70: 91-102.

Kimmins, J.P., Binkley, D., Chatarpaul, L. and de Catanzaro, J. 1985. *Biogeochemistry of temperate forest ecosystems: literature on inventories and dynamics of biomass and nutrients*. Information Report PI-47E/F. Canadian Forestry Service.

Korea Forest Service 2001. *Statistics Yearbook*, Korea Forest Service, Daejon.

Kwak, Y.S. and Kim, J.H. 1992. Nutrient cyclings in Mongolian oak (*Quercus mongolica*) forest. *Korean Journal of Ecology* 15: 35-46.

Lee, D.K. and Kim, G.T. 1997. Tree form and biomass allocation of *Quercus* species, *Larix leptolepis* (Sieb. et Zucc.) Gordon and *Pinus koraiensis* Sieb. et Zucc. in Kwangju-Gun, Kyonggi-Do. *Journal of Korean Forestry Society* 86: 208-213.

Lee, K.J. and Park, I.H. 1987. Primary production and nutrients distribution in 22-year-old *Pinus koraiensis* and *Quercus mongolica* stands in Kwangju district. *Journal of Korean Forestry Energy* 7: 11-21.

Lee, S.W. and Park, K.H. 1986. Biomass and organic energy production in pine and oak natural forest ecosystem in Korea. *Journal of Korean Forestry Energy* 6: 46-58.

Mun, H.T. 1991. Nitrogen mineralization and dynamics in the forest soil. *Korean Journal of Ecology* 14: 317-325.

Mun, H.T. and Joo, H.T. 1994. Litter production and decomposition in the *Quercus acutissima* and *Pinus rigida* forests*. Korean Journal of Ecology* 17: 345-353.

Mun, H.T., Kim, C.M. and Kim, J.H. 1977. Distribution and cyclings of nitrogen, phosphorus and potassium in Korean alder and oak stands. *Korean Journal of Botany* 20: 109-118.

Olson, J.S. 1963. Energy storage and balance of producers and decomposers in ecological systems. *Ecology* 44: 322-331.

Park, B.K. and Kim, M.R. 1985. The decomposition rate of litter and soil microorganisms on slope directions. *Korean Journal of Ecology* 8: 31-37.

Park, B.K. and Lee, I.S. 1980. Effects of habitat and nutrient content of leaves on the litter decomposition of *Larix kaempferi* and *Quercus serrata* at Kwangnung. *Korean Journal of Botany* 23: 45-48.

Park, G.S. and Lee, S.W. 2001. Biomass and net primary production of *Quercus variabilis* natural forest ecosystems in Gongju, Pohang, and Yangyang areas. *Journal of Korean Forestry Society* 90: 692-698.

Park, G.S. and Lee, S.W. 2002. Biomass and net primary production of *Quercus serrata* natural stands in Kwangyang, Muju, and Pohang areas. *Journal of Korean Forestry Society* 91: 714-721.

Park, I.H. and Moon, G.S. 1994. Biomass, net production and biomass estimation equations in some natural *Quercus* forests. *Journal of Korean forestry Society* 83: 246-253.

Park, I.H., Lee, D.K., Lee, K.J. and Moon, G.S. 1996. Growth, biomass and net production of *Quercus* species. I. With reference to natural stands of *Quercus variabilis, Q. acutissima, Q. dentata,* and *Q. mongolica* in Kwangju, Kyonggi-Do. *Journal of Korean Forestry Society* 85: 76-83.

Park, I.H., Seo, Y.K., Kim, D.Y., Son, Y., Yi, M.J. and Jin, H.O. 2003. Biomass and net production of a *Quercus mongolica* stand and a *Quercus variabilis* stand in Chuncheon, Kangwon-do. *Journal of Korean Forestry Society* 92: 52-57.

Son, Y. and Lee, I.K. 1997. Soil nitrogen mineralization in adjacent stands of larch, pine and oak in central Korea. *Annals of Forest Science* 54: 1-8.
Son, Y., Kim, Y.K., Kim, J.S. and Kim, Z.S. 1993. Aboveground biomass, and leaf area and sapwood relations of *Quercus variabilis* in Yangpyeong, Kyonggi Province. *Korea University Research Bulletin of Natural Resources* 33: 13-18.
Son, Y., Kim, J.T., Lee, S.E. and Lee, I.K. 1995. Differences of nitrogen mineralization in *Larix decidua, Pinus strobus* and *Thuja occidentalis* plantations of the Kwangneung Experimental Forest, Kyonggi Province. *Korean Journal of Ecology* 18: 385-395.
Son, Y., Lee, W.K., Lee, S.E. and Ryu, S.R. 1999. Effects of thinning on soil nitrogen mineralization in a Japanese larch plantation. *Communications in Soil Science and Plant Analysis* 30: 2539-2550.
Song, C.Y. and Lee, S.W. 1996. Biomass and net primary productivity in natural forests of *Quercus mongolica* and *Quercus variabilis*. *Journal of Korean Forestry Society* 85: 443-452.
Vogt, K.A., Grier, C.C. and Vogt, D.J. 1986. Production, turnover, and nutrient dynamics of above- and belowground detritus of world forest. Advances in *Ecological Research* 15: 303-377.

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CHAPTER 15

EFFECT OF ORGANIC RICE FARMING ON THE SEASONAL OCCURRENCE OF AQUATIC ANIMALS AND PREDATION EFFICACY OF THE MUDDY LAOCH AGAINST MOSQUITOES IN RICE FIELD

1. INTRODUCTION

Culex tritaeniorhynchus Dyar and *Anopheles sinensis* Wiedemann are distributed widely in Korea and are vectors of JE and of both malaria and inland filariasis, respectively. These mosquitoes are particularly abundant in riceland agroecosystems, where they breed in irrigated rice fields and associated lowland areas. *Anopheles sinensis* and *Cx. tritaeniorhynchus* are the predominant blood-seeking mosquitoes in July and August, respectively (Shim *et al*. 1987, 1990, 1997) and, when present in large numbers, these species present a serious threat to human and animal health through annoyance and as vectors of disease. Because of the threat that *An. sinensis* and *Cx. tritaeniorhynchus* pose to human and animal health, there is a need to develop management programs that will serve to continually keep populations of these species at acceptably low levels. The development and implementation of such programs require a detailed study of the relationship between environmental factors, including natural enemies and various abiotic factors in ecosystems, and the ecology of these mosquitoes.

Traditional mosquito control strategies in conventionally-farmed rice fields used mainly adulticides which include fogging, aerosol sprays and larval control from agro-pesticides in Korea (Ree *et al*. 1981, Shim *et al.* 1995a and b). Each of these methods involves the application of relatively large amounts of insecticides into the environment of the rice ecosystems. These methods also may deposit insecticidal residues in rice that can be taken inadvertently by consumers as well as farmers. Therefore, environmental concerns have stimulated other farming methods to reduce the use of insecticides for controlling pests in rice fields. One approach that has recently gained popularity is organic farming. In Korea, 0.08% of farmers cultivate several crops using organic farming, which utilizes organic fertilizers instead of chemical fertilizers and which does not use pesticides (Paek 1992).

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Geberich and Laird (1968) reported that 253 different fish species possess potential for biocontrol of mosquito larvae. Larvivorous fishes have been used as biological control agents for mosquitoes for nearly 100 years (Meisch 1986). There is renewed interest in the use of larvivorous fishes for mosquito control as an alternative or complement to conventional insecticides in Korea (Yu *et al*. 1981, 1982, Yu 1986, Kim *et al*. 1994). Some of the best mosquito predators investigated during recent years were the predatory fishes, *Aphyocypris chinensis* Gunther, belonging to the family Cyprinidae (Weiser 1991), and *Aplocheilus latipes* (Temminck et Schlegel), belonging to the family Oryziidae. These fishes were evaluated in collaboration with the World Health Organization in laboratory, semi-field and confined field conditions during the period 1979-89 (Yu *et al*. 1982, 1983, 1985, 1986, Yu 1986, Yu and Kim 1989). However, the fish population in rice fields has decreased sharply since the advent of conventional cultivation, insecticide usage, and environmental contamination.

In natural habitats and rice fields in Korea, reduced larval populations of *Anopheles sinensis* Wiedemann and *Culex tritaeniorhynchus* Giles were associated with the presence of muddy loaches, *Misgurnus mizolepis* Gunther, belonging to the Family Cobitidae (Lee *et al*. 1997, Lee 1998). *Misgurnus mizolepis* in organically farmed rice fields breeds in close association with mosquito populations, particularly along irrigation ditches and rice fields. Mosquito larval populations in the presence of *M. mizolepis* were investigated at Bulkyo in southwest Korea. Populations appeared suppressed throughout the mosquito breeding season when compared with control rice fields in the same area. The stocking and/or natural breeding of fish species was a common practice in organically farmed rice fields in Korea. This practice was an additional benefit to farmers, because the fish are a popular food source.

The objectives of this study were to establish the population abundance patterns of vector mosquitoes and other aquatic animals and to evaluate the associations between several environmental factors and the vector mosquitoes in organically-farmed rice versus conventionally-farmed rice. Also, this is a report of a study of the breeding of local fish in rice fields, particularly the widely distributed common species, *M. mizolepis*, and its relation to mosquito populations.

2. MATERIALS AND METHODS

2.1 Organically-Farmed Rice Culture

The study was carried out in the rice field (150 ha) near an estuary, which was less than 2m above sea level, located in Bulkyo, Chullanam-do, Southwestern Korea. In this area, most farmers have used a conventional culture method using chemical fertilizers and insecticides. The insecticides were each applied one time in June and July, and 3 times in August of 1995; but 3 times in early July, and each one time in late July, August and September of 1996. The chemical names of the insecticides used in the field were cartab w.s.p. 50%, fenitrothion E.C. 50%, BPMC

G. 2% and Quratel G. 3%. However, one farmer has cultivated rice since 1980 in the rice field of 3 ha, using an organic culturing method. Each of the four organically- and conventionally-farmed rice paddies for the study were randomly selected from 16 and 850 rice paddies, and each paddy was a 1860 m^2 and 1730 m^2 rectangle, respectively. The conventionally-farmed rice fields were separated from the organically-farmed rice fields by a road and an irrigation ditch connected to a main watering canal and a draining canal. There was no evidence of habitat disruption by either one that would create an effective ecological change in the two different farming conditions. Water was supplied from a reservoir and an underwater spring near the rice fields. A network of irrigation and drainage channels allowed individual water control for each rice paddy and permitted quick flooding and draining by means of an efficient network of parallel ditches connected to them.

The analytical methods given here were based on those given in Field and Laboratory Methods for General Ecology (Brower and Zar 1977). The salinity and pH of water in the two rice field types were measured using a portable salinity meter (NS-3P, Merbabu Trading. Co.) and a portable pH meter (Model TS-1, Suntex Ins.). Once or twice every month, water depths of the rice paddies were measured using a ruler at 10 to 16 different spots. The soil organic matter was analyzed using a method of loss of organic carbon on ignition analysis (Cox 1976). The proportion of soil particles (*e.g.*, clay and silt < 50μm) was determined by the USDA method was used. Also, standard methods were used for examinations of ions in the water. To analyze water contained main ions, the sampled water with soils in each rice field were examined with an UV/VIS spectrophotometer (Model U 3210, Hitachi) and an atomic absorption spectrophotometer (Model Smith-Hieftje 12, Thermo Jarrell Ash).

Four paddies each from organically-farmed and conventionally-farmed rice fields were randomly selected as study plots. The survey was carried out once or twice a month from June to September in both 1995 and 1996, while the rice fields were flooded with agricultural water. The collections were not carried out in other months because the water of the rice paddies was completely drained out in late September. The aquatic animals were randomly collected in each rice paddy. Larval mosquito abundance was monitored by taking water through 16 dips per paddy with a 355ml dipper. Other aquatic animals and benthos samplings were also taken by 32 sweeps with an aquatic net of 32 mesh/cm and 33cm in diameter having a 120 cm wooden handle. Fish samplings in the rice paddies were performed by using an aquarium-type vinyl fish trap (16cm dia. x 20cm long) (Yu *et al.* 1981), placed at 2 sites in each rice paddy.

The samples of three different types from the rice paddies were put into a small plastic concentrator with a fine mesh on the bottom. They were then transferred to 500ml plastic bottles with water and transported back to the laboratory in two ice chests. To minimize physical damage and prevent predators from killing or eating other animals during transportation, the chests were chilled with ice packs. The aquatic animals were identified under a dissecting microscope and a stereo microscope, according to characters described in each specific key of the corresponding taxa (Merritt and Cummins 1984, Stehr 1987a and b, Usinger 1956, Peterson 1982, Fitzpatrick 1983, Yoo 1986, Yoon 1988, Yoon and Ahn 1988a and b, Yoon and Kong 1990).

The physical and chemical characteristics of the soils were statistically compared between the two farming techniques by a Student's *t*-test. In the present study, dominant species, dominance indices and species diversity indices of the organically-farmed rice field were compared with those of the conventionally-farmed rice field in order to analyze the aquatic animal community and the dynamics. The dominance index is a method measuring the simplicity of each community and was here calculated with McNaughton's dominance index (DI) (McNaughton 1967). This index is as follows: $DI=(n_1+n_2)/N$ (N: the total number of individuals in all the species; n_1 and n_2: the numbers of individuals of the 1st and 2nd dominant species, respectively). The species diversity was calculated using the Shannon-Wiener index (H') (Pielow 1969) such as H'=-Sigma p_i log pi, where, $pi=n_i/N$. The pi is the proportion of the total number of individuals occurring in species *i*. Finally, the community similarity was calculated using the Sorensen Coefficient (CCs) (Brower and Zar 1977).

2.2 Predation Efficacy of Fish

Muddy loaches, *M. mizolepis*, used in both laboratory and small rice plot experiments, were indoor and outdoor aquaria stocks originally collected from rice fields and irrigation ditches of Milyang, Kyungsangnam-do, South Korea. Collections began 2 wk prior to the beginning of each experimental series. Aquaria were aerated and supplied with unchlorinated underground water. Fish were fed daily with dog chow complete flake diet during acclimation. The laboratory experiment was performed to determine whether *M. mizolepis* preys on *Culex* mosquito eggs and larvae. The experiment used intermediate-sized fish (1- year old, body length avg. 10 cm and body weight avg. 5 g). A single healthy, unsexed fish was placed into each of 4 glass 14.3-liter aquaria, 30.2 cm in diameter. Underground water was maintained at a depth of 20 cm, with continuous aeration. The colonies of *Culex pipiens pallens* Coquillett larvae and eggs that were used in the experiments were from a laboratory stock maintained at Kosin University. Five hundred 3rd-stage larvae, or 20 egg rafts, of *Cx. pipiens pallens* from the mosquito colony were introduced with an adequate supply of dog chow powder for food. The mosquito larvae or egg rafts in each test aquarium were examined subsequently to determine the number and condition at a temperature of 25 ± 2°C at 24 and 48 h, in comparison with those of the control aquaria. Four replicates were tested for treatment and control.

The semi-field experiment involved testing whether *M. mizolepis* would prey on larvae of *Aedes togoi* (Theobald), *Cx. pipiens pallens*, and *Culex inatomii* Kamimura and Wada larvae under field conditions. A confined semi-field assessment was conducted from June to September, 1997 in small plots planted with rice constructed in an open field at Kosin University. The 6 rice plots were made from fiberglass containers (1.2 x 0.8 x 0.5 m) and were filled with silt soil from natural rice fields to a depth of ca. 15 cm, and with underground water to a depth of 8 cm above the soil. Rice transplantation was accomplished 1 month before fish introduction in late June.

Mosquito larvae of *Ae. togoi* and *Cx. inatomii* were collected from rock pools in Pusan and from a marsh in Woolsan in southeast Korea.

The small rice plots were selected randomly for *M. mizolepis* release at rates of 1, 2, 4, 8, 16 fishes, with 1 left as a control. After 1 week, all dragonfly nymphs were removed, and 1,200 3rd-stage larvae of *Ae. togoi* were introduced into the plots. Mosquito larvae present in the rice plots were counted and recorded 12, 24, 36, 48 and 60 h after introduction and compared with those of the control plot. This test was repeated 5 times.

The 2nd experiment focused on determining predation efficacy of *M. mizolepis* against *Cx. pipiens pallens* and *Cx. inatomii* larvae in the semifield condition. For this experiment, intermediate *M. mizolepis* (body length 10 cm) were released in each small rice plot. After 1 wk, 1,200 3rd-stage larvae of both *Cx. pipiens pallens* and *Cx. inatomii* were introduced into the rice plots. Mosquito larvae were counted, recorded and compared with those of a control plot. The experiment was replicated 5 times. All data were analyzed using Duncan's multiple range test (Ott 1984).

3. RESULTS AND DISCUSSION

3.1 Organically-Farmed Rice Culture.

Rice culturing practices affected the seasonal occurrence of *An. sinensis* and *Cx. tritaeniorhynchus* as well as other aquatic animals. The observed schedule for rice cultivation in the conventional and organic rice fields changed little during the study period, except for minor adjustments caused by the making of a road near the rice fields in May, 1996. In both 1995 and 1996, plowing began at both fields in early May, and water was introduced between the end of May and the beginning of June. The rice plants were grown from transplanting rice seedlings. The seedling transplantation was completed within a week in early June of both 1995 and 1996.

In the conventionally-farmed rice field, chemical fertilizers were distributed in late May of both years to supply phosphate, potassium and nitrogen with a herbicide before transplanting rice seedlings. Also, depending on rice conditions, pesticides were sprayed 5-6 times during the growing season from June to September. The pesticides used were cartap and carbofuran for the control of agricultural pests such as the rice stemborers, the brown planthoppers, the rice green leafhoppers, the smaller brown leafhoppers and the grass leafrollers. In the organically-farmed rice field, an organic fertilizer was supplied once in late May before transplanting rice seedlings. The organic fertilizer was made mainly from a mixture of chicken dung, rice brans and sawdust at the ratio of 6:3:1, respectively. However, no pesticide was applied in the rice field during a year.

The physical characteristics of the soil and the rice field water of two rice fields are shown in Table 1. Some abiotic factors, such as water pH, water salinity, depth of water, various water ions, organic matter and texture of soil were not significantly different between the organically-farmed and the conventionally-farmed rice fields, except for the concentration of P_2O_5 in the water. The water salinities of both the

organically-farmed and the conventionally-farmed rice fields appeared somewhat higher than those of other rice fields: 0.4‰ and 1.9‰, respectively. The reason might be that the rice fields are located near an estuary. The concentration of phosphoric acid (P_2O_5) in the organically-farmed rice field water (173.0 ppm) was significantly higher than that of the conventionally-farmed rice fields (65.5 ppm), due to a farmer's use of chicken dung as a natural fertilizer.

Table 1. Physical and chemical factors of soil and water in the conventionally-and organically-farmed rice fields, 4 - 16 replicates (Lee 1998).

Factor	*Rice Fields (Mean ± S.D.)*	
	Conventional	*Organic*
Water		
pH	5.6a[1] ± 0.10	5.4a ± 0.10
Salinity (‰)	1.1a ± 1.20	0.4a ± 0.10
Depth(cm)	7.2a ± 2.10	6.8a ± 1.43
Soil		
Soil Texture[2] (%)	59.9a -	73.0a -
Organic Matter(%)	4.1a ± 0.20	4.4a ± 0.20
pH	6.0a ± 0.60	6.3a ± 1.00
Na^+ (ppm)	47.5a ± 16.57	52.4a ± 17.62
K^+ (ppm)	27.0a ± 23.37	27.8a ± 25.97
Mg^{2+} (ppm)	3.6a ± 1.49	8.1a ± 13.63
Ca^{2+} (ppm)	0.1a ± 0.10	0.1a ± 0.08
SO_4^{2-}(ppm)	35.7a ± 6.46	32.6a ± 7.93
PO_4^{3-}(ppm)	1.9a ± 0.41	2.3a ± 0.37
P_2O_5 (ppm)	65.5b ± 10.61	173.0a ± 32.53

[1] Means within a row followed by the same letters were not significantly different (P > 0.05; t-test).
[2] Soil percentage indicates particles < 50µm in diameter.

Chemical components of the environment importantly affect the abundance and distribution of species (Brower and Zar 1977). However, there was no evidence that the phosphoric acid affected the abundance and distribution of mosquito larvae or other aquatic organisms. Ikemoto and Sakaki (1979) reported that there was a positive correlation between the number of larvae and the concentration of NH_4-H in the water among the characteristics of water such as temperature, water quantity, pH, DO content and NH_4-H concentration.

There are few reports on the population dynamics of aquatic invertebrates other than mosquitoes and the relationships among them in Korea, as particularly related to the various aquatic animals in organically-farmed rice fields, as well as the insecticide application in conventionally-farmed rice fields. Table 2 shows the number of the aquatic animal taxa from organically- and conventionally-farmed rice fields in 1995 and 1996. The aquatic animal taxa showed a total of 25 species in 22 Families and 10 Orders or Subclasses, such as Ephemeroptera, Odonata, Hemiptera,

Coleoptera, Diptera, Branchiopoda, Ostracoda, Copepoda, Mesogastropoda and Pisces, from the organically- or conventionally-farmed rice fields of Bulkyo from June to September, 1996 (Table 2). The monthly occurrence of species numbers at the rice fields ranged from 14 to 24 species during this period. The vector mosquito species in those rice fields were *An. sinensis* and *Cx. tritaeniorhynchus*. More species (24) of aquatic animals were collected from the organically-farmed rice field than (20) from the conventionally-farmed rice field.

Table 2. Number of the aquatic animal taxa from the organically-farmed and conventionally-farmed rice fields of Bulkyo from June through September, 1995 and 1996 (Lee 1998).

Rice fields	*1995*				*1996*			
	Order	*Family*	*Genus*	*Species*	*Order*	*Family*	*Genus*	*Species*
Organic	7	12	14	14	10	22	23	24
Conventional	6	9	10	11	10	17	19	20
Total	7	12	15	16	10	22	24	25

Shim *et al.* (1995 a, b) concluded that both species - *An. sinensis* and *Cx. tritaeniorhynchus* - have developed a high resistance to most of the pesticides which have been applied to conventionally-farmed rice fields, so that their prevalence was generally not influenced by the pesticides. In the case of the predators of mosquito larvae, such as fish and insect predators, however, it was observed that in the conventionally-farmed rice field, the pesticide application acted as one of the main mortality factors. Other reports give similar results on the population dynamics of aquatic invertebrates other than mosquitoes, as particularly related to insecticide application in rice fields. Service (1977) studied mortalities of *An. gambiae* larvae and other aquatic insects in rice fields in Kenya before and after spraying Dimecron [0, 0-dimethyl-0-(diethylanido-1-chloro-crotnyl) phosphate] applied for the control of rice stem borer. Whereas before spraying there was a very rich and numerous aquatic fauna, exceedingly few live invertebrates remained after spraying. The larval densities of *An. gambiae* 14 days after spraying were significantly larger than pre-spray densities, whereas aquatic invertevrates were not as earlier. In spite of the lack of quantitative data, it was clear that spraying with Dimecron drastically reduced the numbers of aquatic insects whereas recolonization was rapid with *An. gambiae*.

Simpson (1949) and McNaughton (1967) considered not only the number of species and the total number of individuals, but also the proportion of the total that occurs in each species. A collection of species with high diversity will have low dominance. The dominance indices of the rice fields showed a little fluctuation in 1996 (Table 3). The values of dominance index ranged between 0.48-0.96 in the organic rice field, and between 0.52-0.93 in the conventional rice field that the range of dominance was not so different between the rice fields. *Chironomus* sp. was frequently the dominant species in both rice fields during the period of rice cultivation. In the conventionally-farmed rice field, individual numbers of *An.*

sinensis in July and *Cx. tritaeniorhynchus* in September were very large. *An. sinensis* and *Chironomus* sp. appeared to be dominant species at both rice fields, and were especially abundant in early July, 1996. Also, *An. sinensis* was a dominant mosquito species in the conventionally-farmed rice field during July. The populations of *Cx. tritaeniorhynchus* increased at both fields in September although these mosquito larvae were not the dominant species. The abundance of Chinese muddy loaches, *Misgurnus mizolepis* (Gunther) (Cypriniformes: Cobitidae), showed smaller fluctuations than did the mosquitoes in the organically-farmed rice field.

Table 3. Dominant species and their dominance indicies (DI) of the aquatic animal communities at the organically- and conventionally-farmed rice fields in Bulkyo from June through September, 1996 (Lee 1998).

Date	*Rice Field*	*Dominance species*	*DI*
Jun. 19	Organic	*Sigara sp.* (Hemiptera: Corixidae)	0.51
		Misgurnus mizolepis (Cypriniformes: Cobitidae)	
	Convent.	*Chironomus* sp. (Diptera: Chironomidae)	0.85
		Sigara sp. (Hemiptera: Corixidae)	
Jul. 10	Organic	*Chironomus* sp. (Diptera: Chironomidae)	0.83
		Anopheles sinensis (Diptera: Culicidae)	
	Convent.	*Chironomus* sp. (Diptera: Chironomidae)	0.52
		Anopheles sinensis (Diptera: Culicidae)	
Jul. 25	Organic	*Chironomus* sp. (Diptera: Chironomidae)	0.96
		Sigara sp. (Hemiptera: Corixidae)	
	Convent.	*Chironomus* sp. (Diptera: Chironomidae)	0.93
		Anopheles sinensis (Diptera: Culicidae)	
Aug. 21	Organic	*Cercion hieroglyphicum* (Odonata: Coenagrionidae)	0.57
		Chironomus sp. (Diptera: Chironomidae)	
	Convent.	*Chironomus* sp. (Diptera: Chironomidae)	0.87
		Hebrus nipponicus (Hemiptera: Hebridae)	
Sep. 12	Organic	*Hebrus nipponicus* (Hemiptera: Hebridae)	0.48
		Chironomus sp. (Diptera: Chironomidae)	
	Convent.	*Hebrus nipponicus* (Hemiptera: Hebridae)	0.87
		Chironomus sp. (Diptera: Chironomidae)	

Yet, this fish was a dominant species only in June of both years. *Sigara* sp. was frequently a dominant species in the organically-farmed rice fields in 1996, but after early July they did not appear to be a dominant species in the conventionally-farmed rice field. Also, *Cercion hieroglyphicum* and *Hebrus nipponicus* were dominant species at both rice fields in August and September. The aquatic insects might have been impacted by the predators in the organic farm and insecticides in the conventional farm.

Aquatic animal communities in the organically-farmed rice fields were more diverse than those in the conventionally-farmed rice fields, possibly because of various insecticide applications in the conventional rice field. The values of species diversity index ranged from 0.15 in late July to 0.86 in September in the organic rice field and from 0.24 in late July to 0.39 in June and August in the conventional rice field during 1996 (Table 4). In late July, the species diversity indices of both fields were the lowest, which might have been caused by a heavy rainy season. The average of the species diversity at the organic farm (0.62) was almost twice as much as that of the conventional farm (0.35). The majority of living aquatic animals probably less tolerate the chemicals than mosquito larvae in rice fields (Ree *et al*. 1981, Shim *et al*. 1985, 1995a, b). Furthermore, the effect of pesticides might have been evident on the predator populations because development rates of the predators are slower and life histories differ appreciably from the comparatively rapidly developing and fast colonizing mosquitoes (Service 1977). In 1996, the community similarities were the highest (0.42) in September before harvest but the lowest (0.28) in early July. These results might be caused by polyphagous Chinese muddy loaches and King mud snails in the organically farmed rice paddies. The average of the similarities (0.33) showed dissimilar communities between the rice field ecosystems during the year.

Table 4. Species diversity (H') and community similarity (CCs) of the aquatic animal communities in the organically-farmed and conventionally-farmed rice fields in Bulkyo, 1996 (Lee 1998).

Month Date	*Species diversity (H')*		*Community Similarity(CCs)*
	Organic	*Conventional*	
Jun. 19	0.74	0.39	0.29
Jul. 10	0.53	0.36	0.28
Jul. 25	0.15	0.24	0.32
Aug. 21	0.81	0.39	0.35
Sep. 12	0.86	0.37	0.42
Average	0.62	0.35	0.33

The results of the monthly or biweekly prevalencies of *An. sinensis*, *Cx. tritaeniorhynchus* and Chinese muddy loaches are summarized in Figures 1, 2 and 3, respectively. The population of *An. sinensis* larvae appeared from early July, which was much earlier than that of *Cx. tritaeniorhynchus,* and kept a rather constant seasonal prevalence, showing an unusual peak in the middle of September (Fig. 1). The larvae of *Cx. tritaeniorhynchus* were found from the middle of August until the middle of September. This resulted from the complete drainage of the water from both rice fields. As shown in the Figure 2, the population of this species increased

this species in the rice fields during September. The mosquito larval populations of *An. sinensis* and *Cx. tritaeniorhynchus* in the organically-farmed rice field were generally much lower than those in the conventional rice field throughout the period. The Chinese muddy loaches, *Misgurnus mizolepis,* were collected mostly in the organically-farmed rice paddies during the survey period (Fig. 3). The population dynamics of those fish, who were predators of the mosquitoes, were difficult to assess with accuracy. It is not clear whether the density itself is low or the collection method is inadequate for fish populations. The number of this species appeared much smaller than the actual density, and is only reliable for the relative density for the field comparison because the fish are active in night time, yet they were collected using fish traps in daytime. No mortality was observed for the Chinese muddy loaches even during the draining out of the organically-farmed rice paddies and over the winter. On the other hand, some mortality was observed for both young and adult Chinese muddy loaches in the conventionally-farmed rice paddies just after insecticides were applied. The population of this species in the conventional rice field seemed to be deeply affected by insecticide applications showing only 0.3, 0.0, 0.0, 0.0 and 1.0, compared to 3.3, 3.0, 4.5, 4.0 and 4.0 in the organically-farmed rice field in June, early July, late July, August and September of 1996, respectively.

Four insecticides were used in the conventionally-farmed rice field to control mainly the Pyralid moth larvae and the Delphacid planthoppers. The results showed that the monthly populations of *Misgurnus mizolepis* in the conventional rice fields were seriously suppressed by insecticide application, and their recovery was not observed. *Hydaticus grammicus* (Coleoptera: Dytiscidae) was collected in the rice fields during the study period.

Both adults and larvae of this species seemed very susceptible to the insecticide application, as abundance markedly decreased whenever the insecticides were applied to the conventional rice fields.

The populations of other aquatic animals were not significantly different between the organic and the conventional farming of rice fields, except for *Cloeon dipterum* (Ephemeroptera: Baetidae) and *Cercion hieroglyphicum* (Odonata: Coenagrionidae). However, it is not clear whether the fluctuation was due to insecticide pressure or due to inadequate sampling methods. It probably resulted from the insecticide treatments in the conventionally-farmed rice field. Most predatory insect species were not affected by the decrease of *An. sinensis* and *Cx. tritaeniorhynchus* larval populations in the rice fields (Table 5).

The populations of Odonata nymphs (*Cercion hieroglyphicum* and *Sympetrum darwinianum*) were not closely related to the mosquito larval populations. The correlation coefficients of *Cercion hieroglyphicum* against *An. sinensis* and *Cx. tritaeniorhynchus* were -0.25 and 0.04, respectively. The coefficients of *Sympetrum darwinianum* against the vector mosquito species were 0.21 and 0.63, respectively. Also, *Sigara* sp. (Hemiptera: Corixidae), *Helochares striatus* (Coleoptera: Hydrophilidae) and King snails, *Ampullarius insularus* did not significantly reduce the mosquito populations. On the other hand, *Hydaticus grammicus* (Coleoptera: Dytiscidae) related inverse with the mosquito populations, as the correlation coefficients were -0.38 with *An. sinensis* and -0.44 with *Cx. tritaeniorhynchus*. The population of mosquito larvae in the rice fields might have been influenced largely

by oligophagous Chinese muddy loaches, *Misgurnus mizolepis*. The coefficients of correlation between Chinese muddy loaches and the population of mosquito larvae showed the highest correlation: -0.66 in *An. sinensis* and -0.47 in *Cx. tritaeniorhynchus*.

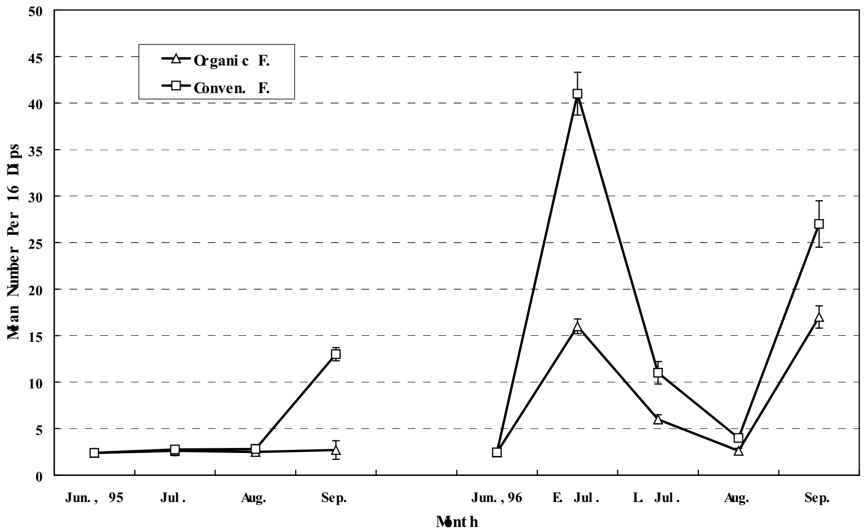

Figure 1. Seasonal prevalence of Anopheles sinensis larvae in the organically- and conventionally-farmed rice fields in 1995 and 1996 (Lee 1998).

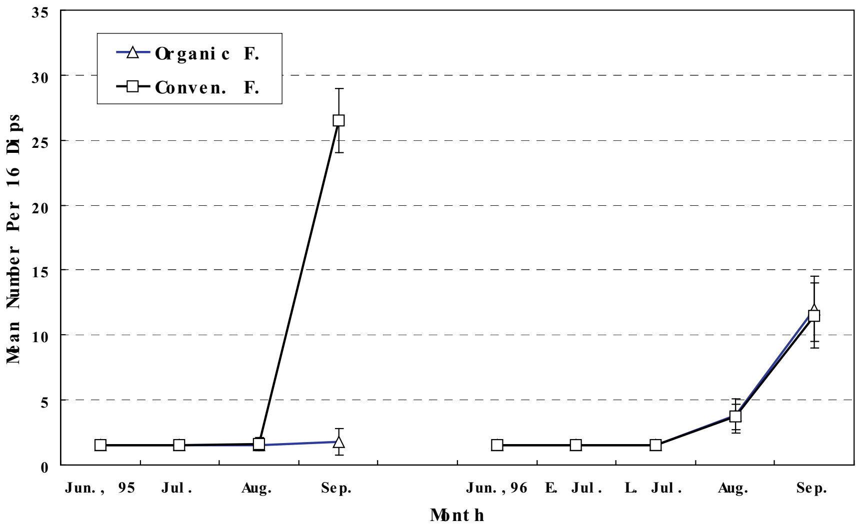

Figure 2. Seasonal prevalence of Culex tritaeniorhynchus larvae in the organically- and conventionally-farmed rice fields in 1995 and 1996 (Lee 1998).

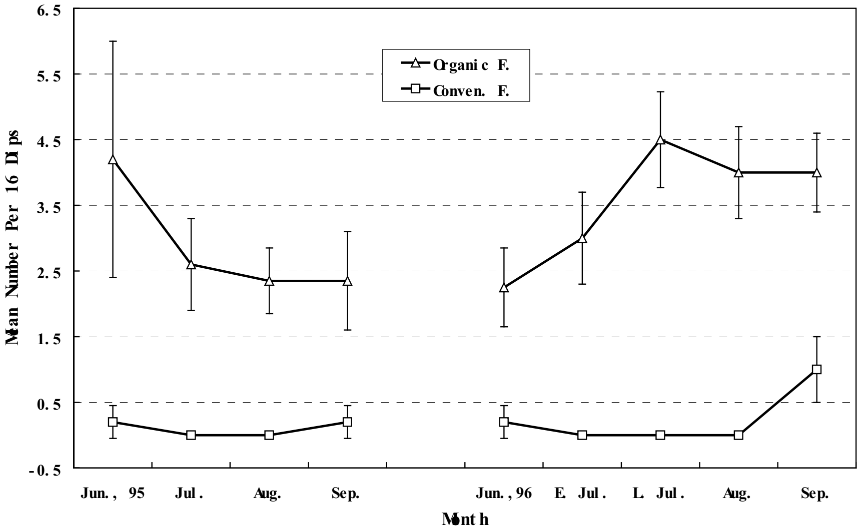

Figure 3. Collection of Chinese muddy loaches, Misgurnus mizolepis in the organically Conventionally- farmed rice fields in 1995 and 1996 (Lee 1998).

Table 5. Association between the aquatic predators and the population of mosquitolarvae in the organically-farmed rice fields of Bulkyo (Lee 1998).

Species	*Correlation*					
	An. sinesis			*Cx. tritaenior*		
	n	*r*	*p*	*n*	*r*	*p*
Cercion hieroglyphicum (Odonata:Coenagrionidae)	8	-0.25	0.274	4	0.04	0.478
Symprtrum darwinianum (Odonata: Libellulidae)	8	0.21	0.305	4	0.63	0.186
Sigara sp. (Hemiptera: Corixidae)	8	0.01	0.490	4	0.84	0.082
Hydaticus grammicus (Coleoptera: Dytiscidae)	8	-0.38	0.177	4	-0.44	0.279
Helochares striatus (Coleoptera: Hydrophilidae)	8	-0.10	0.404	4	0.88	0.059
Ampullarius insularus (Mesogastropoda)	8	-0.26	0.267	4	0.13	0.437
Misgurnus mizolepis (Cypriniformes: Cobitidae)	5	-0.66	0.111	5	-0.47	0.211

It has shown that there are not many effective control methods against adult mosquitoes because of their outdoor feeding, resting habits and the socio-geographical condition (Ree *et al*., 1981, Shim *et al*., 1987). Therefore, studies on population dynamics of immature stages of the vectors are urgently needed, and considered to be essential for effective control. It is important to understand the factors regulating natural populations, particularly agricultural pesticides and predators such as fish, adults and/or nymphs of Coleoptera, Hemiptera and Odonata

and many others, which are found in rice fields in Korea. Several entomologists provided information on the control of these species with particular reference to the impact of rice culture on the bionomics and natural enemies of these mosquitoes. It is apparent that some natural enemies play an important role in regulating the population densities of the mosquito larvae.

Wada (1975) carried out the experimental study, showing that either Odonata nymphs or Notonectidae (Coleoptera) nymphs, or both, are important in reducing the *Cx. tritaeniorhynchus* larvae. Service (1977) collected large numbers of potential aquatic predators from rice fields and identified by serological techniques their predatory feeding habits.

A broad diversity of invertebrate predators of mosquito larvae in their habitats has been reported in the literature (Jenkins 1964, Bay 1974, Collins and Washino 1985). Among them, the most abundant predators were Coleoptera and Hemiptera. Larvivorous fish have been a biological tool for mosquito abatement for nearly 100 years in U.S. (Meisch 1985).

Yu *et al.* (1981, 1982, 1983) and Yu and Lee (1985) proved experimentally that the native fish *Aphyocypris chinensis* and *Aplocheilus latipes*, which had been very common in rice fields in Korea until 1985, are effective predators of mosquito larvae and potential biological control agents. According to the report of Kim *et al*. (1994), the introduction of other species of muddy loaches, *Misgurnus anguillicaudatus,* at 2 fish/m^2, produced a 47.7% reduction *An. sinensis* larvae in a simulated rice paddy over 5 weeks. A marked reduction of mosquito abundance was observed at all organically-farmed rice fields and might have been caused by the Chinese muddy loaches. These results indicated that *Misgurnus mizolepis* is a promising biological control agent for use against several mosquito larvae species breeding in the rice fields of Korea.

3.2 Predation Efficacy of Fish

Five hundred *Cx. pipiens pallens* larvae, or 20 egg rafts, exposed to *M. mizolepis* in a glass aquarium in the laboratory experiment were readily preyed upon by muddy loaches. Intermediate-sized *M. mizolepis* consumed an average of 499.5 of the 500 larvae of 3rd-stage *Cx. pipiens pallens*. Predation had reached 100.0% after 48 h (Table 6).

The muddy loaches consumed and spat out an average of 45 dead larvae. Muddy loaches remained on the bottom of the aquaria most of the time. The fish moved actively to the water surface in order to search for prey and exchange gases both day and night although this fish is known as a nocturnal species.

According to Park *et al*. (1995), the *Misgurnus* species exchanges gases through its gills and intestines, taking air in from its mouth at the water surface and releasing it through its anus. *Misgurnus mizolepis* consumed all 20 *Cx. pipiens pallens* egg rafts by 24 h, whereas no mortality of larvae or egg rafts were observed in the control glass aquaria.

Table 6. Cumulative average number of 500 3rd- stage larvae or 20 egg rafts of Culex pipiens pallens consumed by an intermediate-sized Misgurnus mizolepis in an aquarium after 24 and 48 h (Average of 4 replicates) (Lee 2000).

Exposure Period (h)	*Cumulative number consumed (Mean±SD)*[1]			
	Treatment		*Control*	
	Larvae	*Egg raft*	*Larvae*	*Egg raft*
24	499.4±0.58a	20.0±0.00	0.0±0.00	0.0±0.00
48	500.0±0.00a	-	0.0±0.00	-

[1] Means in the same column followed by the same lower case superscript are not significantly different at the 5% level of probability

In Korea, preliminary screening evaluations of 5 species of fish breeding in rice fields had been previously performed (Yu *et al*. 1982, Yu and Lee 1985). Two species, *A. chinensis* and *A. latipes* were found to have the most potential for mosquito control. In the laboratory, mature fish of *Aphyocypris chinensis* and *Aplocheilus latipes* species consumed an average of 175 and 125 3rd-stage *Cx. pipiens pallens* larvae, respectively, after 24 h. Thus, among fish species bred in the rice fields of Korea, the best biocontrol potential for *Cx. pipiens pallens* appears to be by *M. mizolepis*. Moreover, *M. mizolepis* can survive during dry periods when the rice fields are drained. Kim *et al.* (1994) observed predation by a different species of *Misgurnus*, *M. anguillicaudatus* (Cantor), and reported that at a later stage in maturity, it consumed a higher number of *Cx. pipiens pallens* larvae than the same species of fish at an earlier stage of development.

Two immature *M. anguillicaudatus* consumed 112.7 larvae of 3rd-stage *Cx. pipiens pallens* per day in a 10 liter aquarium, whereas 2 intermediate-sized fish consumed an average of 144 larvae. On the other hand, 2 mature *M. anguillicaudatus* consumed 168.4 larvae per day, which was 49.4% and 16.9% higher than the numbers consumed by immature and intermediate-sized fish, respectively (Kim *et al*. 1994). Thus, an intermediate-sized *M. mizolepis* appeared to consume at least 2.5 or 2.0-fold more *Cx. pipiens pallens* larvae than did intermediate-sized and mature stages 3 respectively, of even 2 *M. anguillicaudatus*. Under semifield conditions, *M. mizolepis*, at 5 different release rates of 1, 2, 4, 8 and 16 fish per plot, preyed on 1,004, 1,197, 1,198, 1.200, and 1,200 after 12 h, respectively, after 1,200 larvae of 3rd-stage *Ae. togoi* were introduced (Table 7). There was a significant difference ($P<0.05$) between the predation rates of the fish at release rates of 1 and 2 fish per plot. All of the 1,200 larvae were consumed by 2 individuals of *M. mizolepis* by 24 h. With the muddy loach introduction, the average numbers of larvae consumed were 1,121.8, 1,195.8, 1,197.0, and 1,200.0 larvae, whereas natural mortalities of 2.0, 2.0, 3.0 and 5.0 larvae were observed at the control plot after 24, 36, 48 and 60 h, respectively. The predation efficacies of *M. mizolepis* against *Cx. pipiens pallens* and *Cx. inatomii* larvae are shown in Table 8. The muddy loach showed a slightly higher predation rate for the 2 species of *Culex* than for *Ae. togoi.* An intermediate-sized *Misgurnus* had consumed 975.8 larvae of

Cx. pipiens pallens after 12 h, 1,192.6 after 24 h, and 1,192.8 after 48 h. Fish consumed 972.2, 1,192.4, and 1,195.8 larvae of *Cx. inatomii* after 12, 24, and 48 h, respectively. After 60 h, all the exposed larvae of both mosquito species in the small rice plots had been consumed by fish. The number of larvae of each mosquito species eaten by the fish after 24 h of exposure may be higher than that of other known mosquito fish in the world.

Misgurnus mizolepis enhanced its value as a mosquito fish by spending a longer duration in rice fields (Lee *et al*. 1997, Lee 1998). Castleberry and Cech (1990) compared the abilities of pupfish (*Cyprinodon nevadensis amargosae*), mosquitofish (*Gambusia affinis*) and guppies (*Poecilia reticulata*) to control mosquitoes in wastewater marshes. All species of fish reduced mosquito larval populations. Muddy loaches also have potential for mosquito control in wastewater sewages and brackish water because of their ability to survive in those environments as well as rice fields in Korea. They can tolerate a wide range of temperatures and low dissolved oxygen levels because of their characteristics of overwintering in water or soil (Lee, unpublished data; Park *et al*. 1995).

The attraction of the muddy loach as a protein source could be used as a positive factor to encourage its use in pisciculture. Muddy loaches have not become harmful in Korean rice ecosystems because of their polyphagous feeding habits. Nevertheless, their role in regulating mosquito populations in rice fields appears to be negligible, although this species of fish is widely distributed and abundant in rice fields in Korea, because populations of *M. mizolepis* were almost completely suppressed by an early application of insecticides against rice stem borers in mid June and never recovered thereafter (Lee *et al.* 1997, Lee 1998). Therefore, it is necessary to carry out further studies on their regulation of mosquito populations under natural conditions.

Table 7. Cumulative average number of 1,200 3rd-stage larvae of Aedes togoi consumed by Misgurnus mizolepis in small rice plots after 12, 24, 36, 48 and 60 h of exposure (22-29°C, 5 replicates) (Lee 2000).

Exposure priod (h)	*Cumulative number consumed (Mean±SD)*					
	No. of Misgurnus mizoplepis used					
	0(Control)	*1*	*2*	*4*	*8*	*16*
12	0.0±0.0	1004.0±12.06b*	1197.0±0.0a	1198.0±0.0a	1200.0±0.0a	1200.0±0.0a
24	2.0±1.6	1121.8±6.4b	1200.0±0.0a	1200.0±0.0a	-	-
36	2.0±1.6	1195.8±1.5	-	-	-	-
48	3.0±1.7	1197.0±1.0	-	-	-	-
60	5.0±2.2	1200.0±0.0	-	-	-	-

* Means in the same row followed by the same lower case superscript are not significantly different at the 5% level of probability (Duncan's multiple range test).

Table 8. Cumulative average number of 1,200 3rd-stage larvae of Culex pipiens pallens and Culex inatomii consumed by 1 Misgurnus mizolepis in small rice plots after 12, 24, 36, 48 and 60 h of exposure (5 replicates) (Lee 2000).

Exposure period (h)	*Cumulative number consumed (Mean±SD)*			
	Cx. pipiens		*Cx. inatomii*	
	Control	*Treatment*	*Control*	*Treatment*
12	0.0±0.0c*	975.8±18.8b	1.4±1.3b	972.2±22.4b
24	0.0±0.0c	1192.6±5.8a	8.8±1.1a	1192.4±7.3a
36	3.8±2.9b	1192.6±5.8a	8.8±1.1a	1195.2±4.6a
48	3.8±2.9b	1192.8±5.4a	10.0±2.5a	1195.8±4.1a
60	7.8±3.6a	1200.0±0.0	10.0±2.5a	1200.0±0.0a

* Means in the same column followed by the same lowercase superscript are not significantly different at the 5% level of probability (Duncan's multiple range test).

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5. REFERENCES

Bay, E.C. 1974. Predator-prey relationships among aquatic insects. *Ann. Rev. Entomol*. 19: 441-453.

Brower, J.E. and Zar, J.H. 1977. *Field and laboratory methods for general ecology*. Wm. C. Brown. Dubuque, 194 pp.

Castleberry, D.T. and Cech, J.J. Jr. 1990. Mosquito control in wastewater: A controlled and quantitative comparison of pupufish (*Cyprinodon nevadensis amargosae*), mosquitofish (*Gambusia affinis*) and guppies (*Poecilia reticulata*) in Sago pondweed marshes. *J. Am. Mosq. Control Assoc*. 6: 223-228.

Central Meteorological Office. 1995. *Daily Meteorological Data*. Apr.-Dec., No. 256.

Central Meteorological Office. 1996. *Daily Meteorological Data*. Apr.-Dec., No. 256.

Collins, F. H. and Washino, R. K. 1985. Insect predators. In H.C. Chapman (Ed.), *Biological control of mosquitoes* (pp.25-42). Am. Mosq. Control Asso. Bull. 6.

Cox, G.W. 1976. *Laboratory manual of General ecology*. 3rd Ed. Wm. C. Brown. Dubuque, 232 pp.

Fitzpatrick, J.F. Jr. 1983. *How to know the freshwater crustacea*. Wm. C. Brown. Dubuque, 227 pp.

Gerberich, J.B. and Laird, M. 1968. Bibliography of papers relating to the control of mosquitoes by the use of fish. In Food and Agriculture Organization of the United Nations Fisheries Tech (Ed.). *An annotated bibliography for the years 1901-1966* (pp. 75:1-70). FAO.

Ikemoto, T. and Sakaki, I. 1979. Physico-chemical characters of the water in rice fields in relation to their suitability for breeding of the mosquito larvae *A. sinensis*. *Jap. J. Saint. Zool*. 30: 87-92.

Jenkins, D.W. 1964. Pathogens, parasites and predators of medically important arthropods. *Bull. WHO*. 30 (Suppl.): 1-150.

Kim, H.C., Kim, M.S. and Yu, H.S. 1994. Biological control of vector mosquitoes by the use of fish predators, *Moroco oxycephalus* and *Misgurnus anguillicaudatus* in the laboratory and semi-field rice paddy. *Korean J. Entomol*. 24: 269-284.

Lee, D.K. 1998. Effect of two rice culture methods on the seasonal occurrence of mosquito larvae and other aquatic larvae and other aquatic animals in rice fields of southwestern Korea. *J. Vector Ecol.* 23: 161-170.

Lee, D.K. 2000. Predation efficacy of the fish muddy loaches, *Misgurnus mizolepis* against *Aedes* and *Culex* mosquitoes in laboratory and small rice plots. *J. Am. Mosq. Contr. Assoc.* 16: 258-261.

Lee, D.K., Jeon, J.H.. Kang, H.S. and Yu, H.S. 1997. Analyses of aquatic ecosystems in organic and conventional farming rice fields and mosquito larval populations. *Korean J. Entomol.* 27: 203-214.

McNaughton, S.J. 1967. Relationship among functional properties of California grassland. *Nature* 216: 168-169.

Meisch, M.V. 1985. *Gambusia affinis affinis*. In H. C. Chapman (Ed.), *Biological control of mosquitoes*. (pp.3-1). Am. Mosquito Control Asso. Bull. 6.

Meisch, M.V. 1986. Mosquito fish offer biological control. *Pest Control* 86: 48-53.

Merritt, R.W. and Cummins, K.W. 1984. *An introduction to the aquatic insects of North America*. Kendal/Hunt Pub. Dubuque, 722 pp.

Ott, L. 1984. *An introduction to statistical methods and data analysis*. Duxbury Press, Boston.

Paek, I.K. 1992. A survey on the production and circulation of low polluted crops. *J. Environ. Pollut. Contr.* 23: 45-49.

Park, H.Y., Yoon, J.M., Chang, K.N. and Heo, H.T. 1995. *Fish biology*. Cheongmoongak. Seoul, Korea

Peterson, A. 1982. *Larvae of insects, Coleoptera, Diptera, Neuroptera, Siphonaptera, Mecoptera, Trichoptera* (Part II), Edwards Brothers. Columbus, 416 pp.

Pielou, E.C. 1969. An introduction to mathematical ecology. Willey-Interscience. New York, 384 pp.

Ree, H.I., Hong, H.K., Shim, J.C. Lee, J.S. Cho, H.W. and Kim, C.L. 1981. A study on seasonal prevalence of the populations of the mosquito larvae and other aquatic invertebrates in rice fields in Korea. *Korean J. Zool*. 24: 151-161.

Service, M.W. 1977. Mortalities of the immature stages of species B. of the *Anopheles gambiae* complex in Kenya: Comparison between rice fields and temporary pools, identification of predators, and effects of insecticide spraying. *J. Med. Ent*. 13: 535-545.

Shim, J.C., Hong, H.K. and Lee, D.K. 1995a. Susceptibilities of *Culex tritaeniorhynchus* larvae (Culicidae, Diptera) to insecticides. *Korean J. Entomol*. 25: 13-20.

Shim, J.C., Hong, H.K., Koo, S.H. and Lee, D.K. 1995b. Susceptibilities of *Anopheles sinensis* larvae (Culicidae, Diptera) to various insecticides. *Korean J. Entomol*. 25: 69-76.

Shim, J.C., Kim, C.L., Lee, W.J. and Shin, E.H. 1990. Population densities of *Culex tritaeniorhynchus* for surveillance of Japanese encephalitis in Korea. *Korean J. Entomol*. 20: 213-222.

Shim, J.C., Shin, E.H., Yang, D.S. and Lee, W.K. 1997. Seasonal prevalence and feeding time of mosquitoes (Diptera: Culicidae) at outbreak regions of domestic malaria (*P. vivax*) in Korea. *Korean J. Entomol*. 27: 265-277.

Shim, J.C., Yoon, Y.H., Kim, C.L., Lee, W.J. and Lim, S.B. 1985. Studies on the effects of pesticides to the vector of J.E. and aquatic animals in rice fields. *Report of NIH Korea* 22: 255-266.

Shim, J.C., Yoon, Y.H., Kim, C.L., Lee, W.J., Lee, B.I. and Kim, S.C. 1987. Integrated control of vector mosquitoes in rice fields. *Korean J. Entomol.* 17: 83-91.

Simpson, E.H. 1949. Measurement of diversity. *Nature* 163: 688.

Stehr, F.W. 1987a. *Immature insects*. Vol. 1, Kendall/Hunt Pub. Dubuque, 754 pp.

Stehr, F. W. 1987b. *Immature insects*. Vol. 2, Kendall/Hunt Pub. Dubuque, 975 pp.

Usinger, R.L. 1956. *Aquatic insects of California*. Univ. of California Press, 508 pp.

Wada, Y. 1975. Culex tritaeniorhynchus. In R. Pal and H. Wharton (Ed.), *Control of Arthropods* (pp.105-118). Plenum Publication.

Weiser, J. 1991. *Biological control of vectors*. Chichester, United Kingdom: Wiley & Sons.

Yoo, J.S. 1986. *Korean shells in colour*. Ilji-Sa. 196 pp.

Yoon, I.B. 1988. *Illustrated encyclopedia of fauna and flora of Korea*. Vol. 30 Aquatic insects. Ministry of Education. 840 pp.

Yoon, I.B. and Ahn, K.J. 1988a. A systematic study of Korean Dytiscidae II, Laccophilinae. *Korean J. Entomol.* 18: 191-195.

Yoon, I.B. and Ahn, K.J. 1988b. A systematic study of Korean Dytiscidae III, Colymbetinae and Dytiscinae. *Korean J. Entomol*. 18: 251-268.

Yoon, I.B. and Kong, D.S. 1990. Systematic study of the dragonfly (Odonata) larva from Korea(I). Superfamily Aeshnoidea. *Korean J. Entomol*. 20: 55-81.

Yu, H.S. 1986. Biological control of malaria vector (*Anopheles sinensis*) by the release of larvivorous fish (*Aplocheilus latipes*) in simulated rice paddies in South Korea. *Korean J. Entomol.* 16: 1-7.

Yu, H.S. and Lee, D.K. 1985. Biological control of mosquito larvae in South Korea using indigenous larvivorous fish. *Proc. Texas Mosq. Control Assoc*. 29: 7-9.

Yu, H.S. and Kim, H.C. 1989. Integrated control of vector mosquitoes with native fishes (*Aplocheilus* and *Aphyocypris*) and *Bacillus thuringiensis* (H-14) in natural rice fields of Korea. *Korean J. Appl. Entomol*. 28: 167-174.

Yu, H.S., Ban, S.J. and Kim, H.C. 1986. Integrated control of encephalitis vector (*Culex tritaeniorhynchus*) by using *Bacillus thuringiensis israelensis* and larvivore *Aphyocypris chinensis* in parsley field, South Korea. *Korean J. Entomol*. 16: 49-56.

Yu, H.S., Kim, H.C., Na, J.O. and Ban, S.J. 1985. Confined field release of native fish (*Aphyocypris chinensis*) and biological control of encephalitis vector (*Culex tritaeniorhynchus*) in marsh of endemic foci area in South Korea. *Korean J. Entomol*. 15:49-55.

Yu, H.S., Lee, D.K. and Lee, W.J. 1982. Mosquito control by the release of fish predator, *Aphyocypris chinensis* in natural mosquito breeding habitats of rice paddies and stream seepage in South Korea. *Korean J. Entomol*. 12: 61-67.

Yu, H.S., Lee, D.K. and Na, J.O. 1983. Biological control of mosquitoes by the release of larvivorous fish, *Aplocheilus latipes* in confined natural rice paddies. *Korean J. Entomol*. 13: 84.

Yu, H.S., Lee, D.K., Na, J. O. and Ban, S.J. 1983. Biological control of mosquitoes by combined use of *Bacillus thuringiensis* var. *israelensis* and larvivorous fish, *Aplocheilus latipes* in simulated rice paddies in South Korea. *Korean J. Entomol*. 13:75-84.

Yu, H.S., Yun, Y.H., Lee, D.K. and Lee, W.J. 1981. Biological control of mosquito larvae breeding in rice paddies in the presence of fish predator, *Aphyocypris chinensis* in Korea. *Korean J. Entomol*. 6: 29-37.

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CHAPTER 16

MODELLING ABOVE-GROUND BIOMASS PRODUCTION OF *PHRAGMITES COMMUNIS* TRIN. STANDS

1. INTRODUCTION

Recently net production of salt marsh plants in Eastern Asia, Northern and Eastern Europe and the Middle East has been measured by several authors (Kim 1975, Bjoerk and Graneli 1978, Min and Kim 1983, Oh and Ihm 1983, Allirand and Gosse 1995). These results were obtained from the peak live standing crop by harvest at regular intervals. Such a method had also been applied to estimation of net production in the plant communities along the Atlantic coastal marsh (Udell *et al*. 1969, Marshall 1970, Jørgenson 1994).

The *Phragmites communis* (common reed) is considered as highly productive, and has a wide global distribution, often present in wet regions as vast homogeneous expanses of reed bads (Pearcy *et al*. 1974, Bjoerk and Graneli 1978, Allirand and Gosse 1995). *P. communis* community grows mostly in fresh but also in brackish and saline water (Ondok 1973, Min and Kim 1983, Oh and Ihm 1983, Ihm *et al*. 2001). They are broadly distributed in the western and southern coast in Korea (Kim *et al*. 1982, Oh and Ihm 1983, Ihm and Lee 1998). These reeds have been utilized to produce non-food commodities, such as paper pulp, roofing and building materials, and in waste-water treatment plants (Bjoerk and Graneli 1978, Graneli 1984, Bjorndahl 1985, Allirand and Gosse 1995).

The stand development and biomass production of *P. communis* have been studied intensively in the field (Haslam 1969a, 1969b, 1970, Dykyjova *et al*. 1970, Kvet 1971, Linden 1980, Dykyjova and Pribil 1975, Fiala 1976, Ho 1979). Such characteristics as CO_2 exchange and salt tolerance have been evaluated in the different locations (Purer 1942, Walker and Waygood 1968, Sieghardt 1973, Gloser 1977, Matoh *et al*. 1988, Cizkova and Bauer 1998, Lissner *et al*. 1999).

In Korea, Kim (1971, 1975) studied the process of plant community formation and standing crops in *P. communis* stands. The productivity of *P. communis* community was studied by Kim *et al*. (1972) in Yeongnam and Kyonggi regions, Min and Kim (1983) in Inchon, and Oh and Ihm (1983) in the Sumjin river estuary.

S.-K. Hong et al. (eds.), Ecological Issues in a Changing World – Status, Response and Strategy 251-259.

Chang and Oh (1977) and Chang *et al*. (1978) studied the litter decomposition in *Phragmites* grassland in the delta of the Nakdong River.

Although many experiments have analyzed the growth dynamics of *P. communis*, few researchers have attempted to analyze the change of the primary production for *Phragmites* species using numerical simulation models (Kim *et al*. 1972, Allirand and Gosse 1995, Asaeda and Karunaratne 2000.).

The purpose of this paper is to analyze the effects of PPFD and air temperature on above-ground biomass production of a well-established *P. communis* stands growing in coastal wetlands in Korea.

2. MATERIALS AND METHODS

The study site is located in Yangwol-ri, Jido-up, Shinan-gun, Cheollanamdo Province in Korea (34°03' E, 126°17' N) (Fig. 1). The site is covered by well-established *P. communis* stands, which are about 3.2 m in height in August. During the last 30 years the observations by Mokpo meterological station near Shinan-gun showed that the annual precipitation is around 1217 mm, 45-60 percent of it comes in summer, and only 3-10 percent in winter.

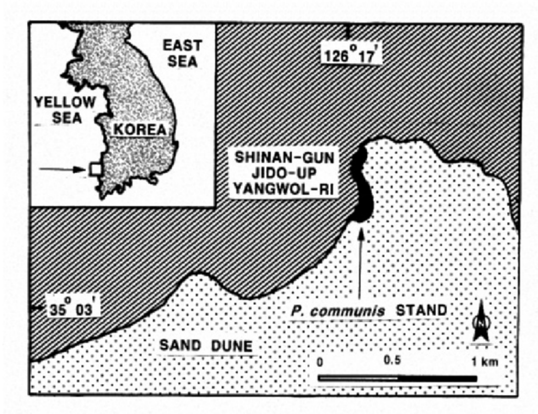

Figure 1. Map showing study site.

The vertical light transmittance within the stand was measured on a ladder at 0.1 m intervals within the canopy at near noon on a fine day (11:00 to 14:00 solar time) in August. To measure horizontal light intensity was established by running string horizontally within a 5 ×5 m quadrat and the light intensity was measured at least 10 times at each intersecting point each height.

The relative light intensity was determined using the method described by Kim (1985). Using above results the vertical and the horizontal light intensity within the canopy were calculated on the basis of the Lambert-Beer Law (Monsi and Saeki

1953, Ondok 1973). Gas exchange of leaves, stems and roots and rhizomes were measured using an infra-red gas analyzer (ADC, UK).

3. RESULTS

3.1. Developing the production model

The model was composed of the compartments of both climatic and biological variables. The former was photosynthetic photon flux density (PPFD), daily maximum- and minimum-temperature. The latter were combinations of the specific physiological responses of plant organs with the biomass of the respective organs (Fig. 2). The PPFD and air temperature was calculated and using their values the gas exchange rate of each plant organ was calculated at every hour. They were summed up as monthly outputs and above-ground biomass production were estimated by monthly net photosynthetic rate.

3.2. Diurnal pattern of climatic variables

The daily PPFD cycle was approximated by the method of Suh (1992) and was corrected by cloud cover according to O'Rourke and Teijung (1981). The daily temperature cycle was approximated by sinusoidal equation using daily maximum- and minimum-values from a nearby meteorological station (Suh 1992, Kim and Kim 1997).

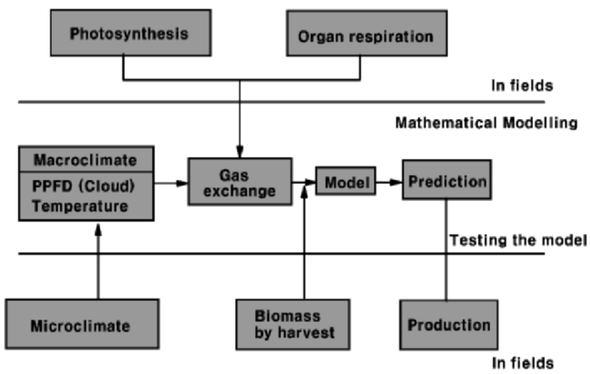

Figure 2. Flow chart showing the experimental design in this study.

3.3. Seasonal change of leaf area

The empirical equation between leaf area (La_t, m^2) and a given day (t) for growing season in a given year was determined by a logistic growth equation.

$$La_t = \frac{K_{La}}{1+\exp(c-rt)} \qquad (1)$$

where c and r are the integration coefficient and the growth coefficient of leaf area in a given year. K_{La} = 4.409 m^2/m^2; c = 2.029; r = -0.0465.

3.4. Respiration of plant organs

The respiration rates of leaves (R_l) in mg CO_2 $dm^{-2}h^{-1}$, stems (R_s) in mg CO_2 $g^{-1}h^{-1}$ and roots and rhizomes (R_r) in mg CO_2 $g^{-1}h^{-1}$ to temperature (T, ℃) were approximated by exponential equations (Fig. 3).

$$R_l = \exp(-2.096 + 0.043\ T) \qquad (2)$$
(r = 0.963)

$$R_s = \exp(-2.742 + 0.044\ T) \qquad (3)$$
(r = 0.965)

$$R_r = \exp(-3.765 + 0.055\ T) \qquad (4)$$
(r = 0.974)

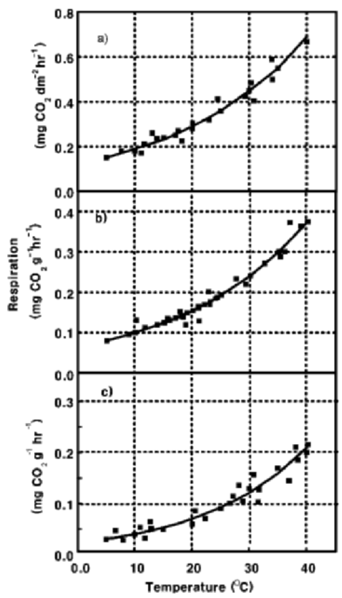

Figure 3. Respiration rate of leaves(a), stems(b) and roots and rhizomes(c) dependent upon temperate in P. communis *Trin*

3.4. Net photosynthetic rate

The net photosynthetic rate $P(Q, T)$ in mg CO_2 $dm^{-2}h^{-1}$ at a given PPFD (Q, mmol quanta $m^{-1}s^{-1}$) and T (℃) can be calculated by Eq. (5), transforming the equation of Potvin *et al*. (1990). The constant f was given as -2.958 by the regression equation between net photosynthetic rate and PPFD at the optimum temperature:

$$P(Q, T) = P_g \{1 - \exp(f \cdot Q)\} - R_l \quad (5)$$

where P_g is gross photosynthetic rate (mg CO^2 $dm^{-2}h^{-1}$).
Assuming that Q is very large or under saturation we may modify Eq. (5) to

$$P(\infty, T) = P_g - R_l = P_x \quad (6)$$

Under saturating PPFD the relation of photosynthetic rate (P_x, mg CO_2 $dm^{-2}h^{-1}$) to T was approximated by the quadratic function (Fig. 4):

$$P_x = -7.646 + 1.710\ T - 0.030\ T^2 \quad (7)$$

Hourly CO_2 exchanges were calculated as changes of hourly environmental conditions and summed as monthly amounts**.**

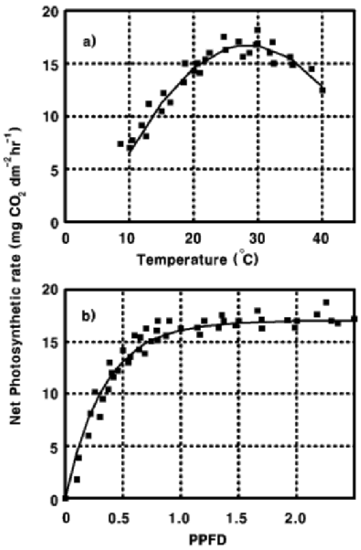

Figure 4. Net photosynthetic rate dependent upon temperate (a) and PPFD (b) in P. communis *leaves.*

3.5. Testing the model

In sensitivity analyses to investigate the change of certain input data, net photosynthetic rate increases proportionally as PPFD increase with canopy. As variable multiplication factor increases from 0.5 to 2.0, net photosynthetic rate inhibited by cloud cover decrease by as little as 10%. The sensitivity coefficients for

gross photosynthetic rate and leaf area index contributed linearly to increase of net photosynthetic rate.

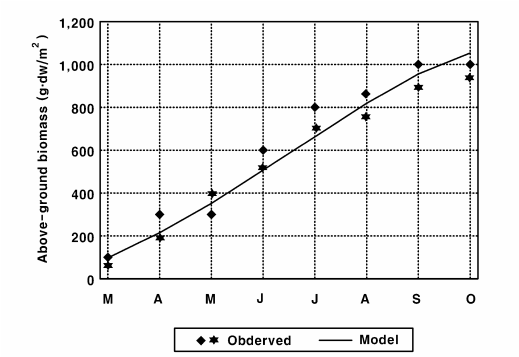

Figure 5. Relationship between the above-ground biomass observed at two stands and the above-ground biomass predicted by the model in P. communis Trin*. Stands.*

Seasonal changes of above-ground biomass observed at study stand and predicted by model is shown in Fig. 5. The highest amounts of above-ground biomass at study stand and in the model were 1,003 and 1,008 g·dw/m^2, respectively, in mid-October (Fig. 5). By the t-test on the null hypothesis that the observed values and the predicted values in the model were same, the null hypothesis was not rejected (P<0.992).

The final result produced promising predictions with regards to the levels of production attained. The model showed the annual above-ground biomass related to both above-ground and below-ground production that increased with increasing annual temperature. We observed that respiration of leaves and stems, as well as of rhizomes and roots, consume a considerable amount of photosynthetic production.

4. CONCLUSION

The application of natural populations of numerical modelling techniques is not frequent. This model confirms that the processes involved and the obtained production levels are analogous for natural and cultivated vegetation (Allirand and Gosse 1995). Many models developed for production in *Phragmites* stands should allow an accurate evaluation of potential under various climatic condition. Application of this model to several species with similar characteristics should be very useful assuming that the parameters are correctly evaluated. One of the weak points of this model is its difficulty in assessing plant reproduction: determination would require the use of several sets of data obtained from a wider range of natural conditions.

Aboveground biomass of *P. communis* stands studied by Kim *et al*. (1972), Kim (1975), Kim *et al.* (1982), Kim *et al*. (1986), Min and Kim (1983) and Oh and Ihm (1983) at various sites in Korea was within a range from 406 g·dw/m^2 at Gunja

which was flooded with the sea water at coast to 6,461 g·dw/m^2 at Eulsugdo which was flooded with brackish water at the estuary of the Nagdong River.

The result of above-ground biomass production model (1,008 g·dw/m^2) in this study was consistent with those of reed bed located south-west of Paris in France by Alligard and Gosse (1995), Muan peninsula by Kim (1975), high tidal salt marsh located on Namdong, Incheon by Min and Kim (1983) and the Sumjin river estuary by Oh and Ihm (1983) in South Korea.

The addition to the potential production model of water, mineral and pathological stress modules are currently under investigation independently from the species under consideration, as there is an obvious need for such work. In the case of the common reed, priority should probably be given to studying the influence of the water table height on rhizome bud production and leaf surface area establishment (Allirand and Gosse 1995).

The model can be used to determine production potential under given climatic conditions and could even be applied to plant canopies with analogous biological characteristics. The removal of dissolved inorganic compounds from domestic and agricultural waste using aquatic plants, such as *P. communis*, are of increasing demand. The concept behind waste-water treatment plants using *P. communis* is to remove mainly nitrogen and phosphorous by harvesting the *P. communis* shoots when they contain their maximum amounts of nutrients. The model, with a further extension to the nutrient budget, has the scope to predict this period, thus enabling it to be used as a management tool to plan the harvesting season.

5. REFERENCES

Allirand, J.M. and Gosse, G. 1995. An above ground biomass production model for a common reed (*Phragmites communis* Trin.) stand. *Biomass and Bioenergy* 9: 441-448.

Asaeda, T. and Karunaratne, S. 2000. Dynamic modeling of the growth *Phragmites australis*: model description. *Aquatic Botany* 67: 301-318.

Bjoerk, S. and Graneli, W. 1978. Energy reeds and the environment. *Ambio* 7: 150-155.

Bjorndahl, G. 1985. Influence of winter harvest on stand structure and biomass production of the common reed *Phragmites australis* (Cav.) trin. ex steud. in Lake Takern, Southern Sweden. *Biomass* 7: 303-319.

Chang, N.K. and Oh, K.H. 1977. The decomposition rates of the organic constituents of the litter in *Phragmites longivalvis* grassland in a delta of the Nakdong-River. *Collection of thesis, Coll. of Education, Seoul National Univ.* 15: 129-142.

Chang, N.K., Oh, K.H. and An, B.H. 1978. The turnover rates of N, P, K, Ca, and Na of the litter in *Phragmites longivalvis* grassland in a delta of the Nakdong-River. *Science Education, Seoul National Univ.* 3: 17-24.

Cizkova, H. and Bauer, V. 1998. Rhizome respiration of *Phragmites australis*: Effect of rhizome age, temperature, and nutrient status of the habitat. *Aquatic Botany* 1998: 239-253.

Dykyjova, D., Ondok, J.P. and Priban, K. 1970. Seasonal change in productivity and vertical structure of reed-stands (*Phragmites communis* Trin.). *Photosynthetica* 4: 280-287.

Dykyjova, D. and Pribil, S. 1975. Energy content in the biomass of emergent macrophytes and their ecological efficiency. *Arch. Hydrobiol.* 75: 90-108.

Gloser, J. 1977. Characteristics of CO_2 exchange in *Phragmites communis* Trin. derived from measurements *in situ*. *Photosynthetica* 11: 139-147.

Graneli, W. 1984. Reed *Phragmites australis* (Cav.) Trin. ex Steudel as an energy source in Sweden. *Biomass* 4: 183-208.

Fiala, K. 1976. Underground organs of *Phragmites communis*, their growth, biomass and net production. *Folia Geobot. Phytotax.* 11: 225-259.

Haslam, S.M. 1969a. The development of shoots in *Phragmites communis* Trin. *Ann. Bot.* 33: 695-709.

Haslam, S.M. 1969b. The development of buds in *Phragmites communis* Trin. *Ann. Bot*. 33: 289-301.

Haslam, S.M. 1970. The development of the annual population in *Phragmites communis* Trin. *Ann. Bot.* 34: 571-591.

Ho, Y.B. 1979. Shoot development and production studies of *Phragmites australis* (cav.) Trin. ex Steudel in Scottish lochs. *Hydrobiologia* 64: 215-222.

Ihm, B.-S. and Lee, J.-S. 1998. Soil factors affecting the plant communities of wetland on southwestern coast of Korea. *Korean J. Ecol.* 21: 321-328.

Ihm, B.-S., Lee, J.-S. and Kim, J.-W. 2001. Coastal vegetation on the western, southern and eastern coast of the south Korea. *J. Plant Biol.* 44: 163-167.

Jørgenson, S.E. 1994. *Fundamental of Ecological Modelling,* 2nd edition. Elsevier. Amsterdam.

Kvet, J. 1971. Growth analysis approach to the production ecology of reed swamp plant communities. *Hydrobiologia* 12: 15-40.

Kim, C.M., Yim, Y.J. and Rim, Y.D. 1972. Studies on the primary production of the *Phragmites longivalvis* community in Korea. *The report for the IBP No. 6. Korean National Committee for the IBP*, pp. 1-7.

Kim, C.S. 1971. An ecological study on the process of plant community formation in tidal land. *Korean J. Bot. (J. Plant Biol.)* 14: 27-33.

Kim, C.S. 1975. A study on standing crops in *Phragmites communis* communities and their environmental factors. *Korean J. Bot. (J. Plant Biol.)* 18: 129-134.

Kim, J.-H. 1985. Canopy architecture and radiation profiles in natural *Typha* × *glauca* stand. *Korean J. Bot. (J. Plant Biol.)* 28: 1-8.

Kim, J.-H., Kim, H.S., Lee, I.K., Kim, J.W., Mun, H.T., Suh, K.H., Kim, W., Kwon, D.H., Yoo, Y.B, Suh, S.A. and Kim, Y.S. 1982. Studies on the estuarine ecosystem of the Nagdong River. *Proc. Coll. Natur. Sci. Seoul National Univ.* 7: 121-163.

Kim, J.-H., Cho, K.J., Mun, H.T. and Min, B.M. 1986. Production dynamics of *Pragmites longivalvis, Carex scabrifolia* and *Zoysia sinica* stand of a sand bar at the Nagdong river estuary. *Kor. J. Ecol.* 9: 59-71.

Kim, J.W. and Kim, J.-H. 1997. Modelling the net photosynthetic rate of *Quercus mongolica* stands affected by ambient ozone. *Ecol. Model.* 97:167-177.

Lissner, J., Schierup, H.-H., Comin, F.A. and Astorga, V. 1999. Effect of climate on the salt tolerance of two *Phragmites australis* populations. II. Diurnal CO2 exchange and transpiration. *Aquatic Botany* 64: 335-350.

Matoh, T., Matsushita, N. and Takahashi, E. 1988. Salt tolerance of the reed *Phragmites communis*. *Physiol. Plant*. 72: 8-14.

Monsi M. and Saeki, T. 1953. Uber den Lichtfaktor in den Pflanzegesellschaften und seine Bedeutung fur die Stoffproduktion. *Jap. J. Bot.* 14: 22-52.

Min, B.M. and Kim, J.-H. 1983. Distribution and cyclings of nutrient in *Phragmites communis* communities of a coastal salt marsh. *Korean J. Bot. (J. Plant Biol.)* 26: 17-32.

Oh, K.-H. and Ihm B.-S. 1983. Seasonal changes in the productivity and soil nutrients of *Phragmites communis* community in the salt marsh of the Sumjin-River estuary. *Korean J. Ecol.* 6: 90-97.

Ondok, J.P. 1973. Photosynthetically active radiation in a stand of *Phragmites communis* Trin. II. Model of light extinction in the stand. *Photosynthetica* 7: 50-57.

O'Rourke, P.A. and W.H. Teijung. 1981. Total stand leaf net photosynthetic rates affected by cloud types and amounts. *Photosynthetica* 15: 504-510.

Pearcy, R.W., Berry, J.A. and Bartholomew, B. 1974. Field photosynthetic performance and leaf temperatures of *Phragmites communis* under summer conditions in Death Valley, California. *Photosynthetica* 8: 104-108.

Potvin, C., M.J. Lechowicz and S. Tardif. 1990. The statistical analysis of ecophysiological response curves obtained from experiments involving repeated measures. *Ecology* 71: 1389-1400.

Purer, E.A. 1942. Plant ecology of the coastal salt marsh lands of San Diego County, California. *Ecol. Monogr.* 12: 81-11.

Sieghardt, H. 1973. Utilization of solar energy and energy content of different organs of *Phragmites communis* Trin. *Pol. Arch. Hydrobiol.* 20: 151-156.

Suh, K.H. 1992. Carbon Dioxide Budget in Oriental Arborvitae (*Thuja orientalis*) Population. Ph.D. thesis. Seoul National University, Seoul.

Udell, H.R., Zarudsky, J., Doheny, T.E. and Burkholder, P.R. 1969. Productivity and nutrient values of plants growing in the salt marshes of the town of Hampstead. Long Island. *Bull. Torrey Bot. Club*. 96: 42-51.

Walker, J.M. and Waygood, E.R. 1968. Ecology of *Phragmites communis*. I. Photosynthesis of a single shoot *in situ*. *Can. J. Bot.* 46: 549-555.

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PART III

ECOLOGICAL NETWORKING AND RESTORATION TECHNOLOGY: THEORY AND PRACTICE

YEONG-KOOK CHOI

CHAPTER 17

LINKING PLANNING SYSTEM BETWEEN SPATIAL DEVELOPMENT PLAN AND ENVIRONMENT PLAN TOWARD SUSTAINABLE DEVELOPMENT

1. INTRODUCTION

1.1 Major Concerns

The core change of spatial development planning in 1993 was to introduce the quasi-agricultural zone by use zoning in order to ease the land use regulation (Choi 2001). Designation of quasi-agricultural zone considers development as well as reservation at the same time, but it enables to secure the use that the development is available at any time. For the past 10 years of rampant national land development, it may be attributable to the designation of quasi-agricultural zone that is ambiguous but completely exposed to "development".

However, even more troublesome is that the consideration for environment in various spatial development plans was only for the “formality”. Many experts claim that the environment has been destroyed and polluted due to the development without careful planning, but none of the developments has been undertaken without planning in advance. Even the poorest planning presents the plan with much of green area that harmonizes with the surrounding scenery on its plan.

However, once developed, we only see the mountains cut open with the clogging of the downstream to show our living environment in worse condition imaginable. The planning report and the policy promotion show the details to reduce the damages to the natural environment caused by development, but the actual enforcement method has yet to be proposed (KRIHS 2001).

While the sceneries have been destroyed and the natural environment is damaging from various developments, the environment plan (MOE 2001a) has been making efforts for "Preservation Plan" to protect the species that have the preservation value but under the danger of extinction. And, in order to clean the polluted water and air, it has been strengthen the standard of pertinent laws and expand various environment-based facilities. However, the environment plan does not consider the removal of mountains and disappearance of forests due to the development.

S.-K. Hong et al. (eds.), Ecological Issues in a Changing World – Status, Response and Strategy 263-299.

Then who shall resolve the damage to the natural environment and disharmony of sceneries that is caused by the spatial development plan? When the spatial development plan is established, the planning establishment period, information and the objective of the plan are made for “development”. And it is not so easy to consider the damage to environment in preparing the spatial development plan under the current situation. In the area where the environment plan is established, it has the importance of preservation value to assert the work scope that it would not wish to involve the natural environment from the development. The importance of nature shall not be determined by the selection of the human decision alone (Jin 1998, Leopold 1966). This is because nature has its own environment to have the living things to live. Regardless of value to human, nature has its own intrinsic value, and when all areas of nature take their own role in ecology, the "important" types of organisms that we value would have the condition to live in (Sagoff 1991).

Under such a point of view, the damages to environment following development shall be treated in the environment plan where the environment conservation is handled. At the same time, it is essential undertaking to consider the environmental problems in the place where the development is to be made (Riedel and Lange 2001). This is the reason to have the two plans to support and supplement in mutual relationship.

Under the recognition that there was a full and complete overhaul on the spatial development plan with the designation of the quasi-agricultural zone as well as due to mistaken development. There was a major overhaul on the laws related to spatial development plan in 2002. From 2003, under the Framework Act on National Territory and the Act on Planning and Use of National Territory (hereinafter, "National Territorial Development Planning Act") newly formulated, the environment-friendly spatial development plan and development are expected.

Under the Framework Act on National Territory, the environment-friendly national land management is emphasized in order to seek continuous development as the basic concept of spatial development plan[i], and the National Territorial Development Planning Act has the principle of 「planning first-development later」 to have the policy of attracting the planned development in planning entire national territory and preventing the rampant development.

In the mean time, in order to clarify the rights and obligations of people and the responsibilities of the government on the environment conservation, and determine the basic vision and direction of environment policy, the Framework Act on Environmental Policy was recently revised (Nov. 8, 2002). Through this, the basis of establishing the national environmental preservation plan to consider the environment in spatial development plan was established. It may be said to secure the basis to involve on the damages to the environment conservation by development.

However, the National Territorial Development Planning Act is still inefficient since it is not much different to the existing system in terms of environmental issues expected following the establishment of various plans (Choi 2001). They present various ways to consider the environment conservation as well as not to allow the

development actions rampantly made, however, they do not have the ways to directly handle the environmental damages arising from the development.

The enforcement decree and plan preparing instruction will present the details to consider the environment and check on them, but the important thing is that they do not present the details of planning that is based on the environment conservation. In addition, the revised the Framework Act on Environmental Policy is not in the level of environment plan that has the linkage with the spatial development plan in mind. There is no real body of environment plan yet, and the system does not contain the matters on what to consider in the environment plan when establishing the spatial development plan.

In the light of view that the spatial development plan and environment plan pursue the same objective in enhancement of quality of life, and when the various spatial development plans are made as an advance preparation and measure to lower the damages to the natural environment and disconnection to the ecology following the development, there is a need of considering the environment plan [ii] at the planning establishment stage (Steiner *et al.* 1988).

In this study, the plan to link the two planning system in the point of view that the environment plan and spatial development plan are linked to prevent the damage to the environment conservation caused by the development and seek the measure to lower the damages.

1.2 Purpose of linking Planning System

The main purpose to link spatial development plan and the environmental planning system is to promote the sustainable spatial management policy. The sustainable spatial management means the spatial development plan and development based upon the environmental considerations. When the national territory is used and developed, the plan to consider environment conservation can be contemplated in several viewpoints. One of the plans is to link spatial development plan and the environmental planning system.

The objective of this study under such a view is to set the direction to link spatial development plan and the environmental planning system and present the ways for it. To link the two plans, all environmental fields shall be handled, but in this study, the focus is on the damages to the natural environment arising in the process of establishing spatial development plan to limit the scope of the environment plan.

In order to fundamentally treat the environment problems caused by the development in spatial development plan such as spatial development plan, there is a need of environment plan that considers the ecological status of national territory more than anything else.

Within such an objective and scope of substantive environment plan, this study seeks the system structuring of the environment plan for liking spatial development plan and the environmental planning system. The areas not handled in this study[iii] are left for further study later.

1.3 Method and Scope of Research

1.3.1 Method

This research was undertaken through the bibliographic study, case study, questionnaire study and others. In particular, the bibliographic study and case study referred mainly to the cases of other countries.

In the bibliographic study, the contents of pertinent laws and existing plan report are reviewed in order to seek the linkage of the existing environment on city and gun (county) plan, National Territorial Development Plan and Comprehensive Provincial Plan, and based on it the limits of existing environment plan and problems under the system are formulated. In addition, planning system of spatial development plans and the environment plans of foreign countries are arranged and analysed to formulate the current issues as well. For the cases of foreign countries, Germany and Japan were primary source of information, and the cases to consider the environment conservation in the course of establishing spatial development plan or considering the environment plan partially are sought herewith. In the case study, the review was mainly made on the landscape ecological plan and biotop mapping preparation and utilization of Germany. In particular, the experience earned through the interviews with related German experts has become an important turning point of broadening the scope of the research. Survey study was collected the opinion on the linkage system of spatial development plan and environment plan with the subject of government employees and related specialists. Here, the survey research had the focus on analysing the problem of current planning system, the difference of opinion of experts on linkage direction for what the research staff thinks and the needs of linkage, rather than to seek new ideas or new plans for the linkage of the two planning system.

1.3.2 Scope

Relevant System and Plan

In this research, the scope of spatial development plan and relevant system[iv] are related system to National Territorial Development Plan, Comprehensive Provincial plan, Metropolitan Urban Plan, and Urban Plan that had the basis on the Basic Act on National Land and other spatial development plan laws. For the existing system, the review was made together with the Act on Comprehensive Planning of Land Construction, Spatial development plan Management Act and Urban Planning Act. The scope of environment plan and relevant system[v] is based on the Long-term Comprehensive Plan for Environment[vi], Basic Plan for Natural Environment Conservation and its related Basic Act on Environment Policy, Natural Environment conservation Act, Environment Effect Evaluation Act and others.

In addition, spatial development plan system is based on the 4 stages of National Territorial Spatial development plan, Comprehensive Provincial Plan, Urban Comprehensive Plan (including the metropolitan urban planning), Urban Management Plan and District Unit Plan. Here, the Urban Comprehensive Plan and

the Urban Management Plan are actually one urban planning stage, but it was classified in two stages for the convenience following the binding effect of the plan. In addition, the district unit plan is a part of the Urban Management Plan for a stage but it is classified in the linkage of the planning system that the needs of separate environment plan stage is decided. Therefore, the environmental planning system is reviewed as spatial development plan system has its stage secured.

Substantive Scope

This research has been progressed with the focuses on how spatial development plan and environment plan treat the issue of environmental damaged following the development, and how these two planning systems should have what relationship. Under the point of view that the resolution of the issue of environmental damage related to landscape ecology would be easier as the relationship of the plan details of these two planning systems come closer that the linkage plan of the two planning systems is reviewed. Accordingly, under this research is to establish the ecological land use planning that is environment friendly spatial development plan, and the substantive scope of spatial development plan is limited in the point of view to consider the ecosystem. Another word, the plan for each field treated under spatial development plan shall consider the environment conservation as much as it could, and for this purpose, the environmental map [vii] that is used in establishing the ecological land use planning, but here, the focus was mainly on the utilization of the biotop mapping. This is attributable to the fact that there is a limit in research period, research staff and the accumulated existing research that makes it difficult to treat all fields including soil, atmosphere, water, atmosphere and others needed in the linkage with the practical environment plan.

Accordingly, the field of environment plan is limited to the matters related to the development. Environment plan is mutually linked with various fields including atmosphere, water quality, waste material, pollution, damage to the natural environment and others, but the damage to the natural environment is mainly treated herewith. Accordingly, spatial development plan in this study treats the scenic planning, environment conservation planning, park and green plan related to the damage to the natural environment following the development. Namely, the scope of research is limited for the point of view to prepare the “spatial development plan” that may prevent or lower the damages to the natural environment and the fragmentation in the ecosystem that has the possibility of occurring from the land use planning, traffic planning and the like. In the meantime, the linkage of spatial development plan and environmental planning system may be considered under the point of view of planning establishment stage, execution, management stage and others, but here, the linkage plan is mainly reviewed in the planning establishment stage.

1.4 Review of Related Literature

As the result of prior research (Choi 2001, Ministry of Environment 2000a, 2001b, 2002), it seems that there is no existing research that presents detailed plan on the

linkage of spatial development plan and the environment plan. However, some expressed an opinion that there is a link needed for the two planning system in order to promote the environment-friendly spatial development plan.

The reason why there was no existing research on the issue can be thought of in two points of view. First is that the experts related to spatial development plan recognized the needs of it but may fear that they lose the justification that spatial development plan system would be given the priority than the plan on all national land management if the two planning systems are linked. Another thought would be that there has not real environment plan to this point that there is no actual body needed in linking the two planning systems and the experts on environment policy had a passive attitude on this. Namely, the environment damage and fragmentation of ecosystem following development was deemed to be the one for the persons undertaking the task of spatial development plan, and in addition, the environment policy was deemed to promote for the space with the value to preserve (Choi 2001).

In most of cases, looking onto the reports pointed out as the content of existing environment plan and systematic problems, the environment plan[viii] is handled in the point of view of environmental policies of projects-oriented and target value oriented under the basic laws of policy and the subject to protect, diversity of organism, endangered species protection that are treated under the Natural Environment conservation Act, that there is no report that reviewed on the point of view of linking on the actual spatial development plan. However, the Ministry of Environment has promoted the basic study for establishing the environmental preservation plan for the national land. This research is a basic study for establishing instruction on the land environment field as a part of national environment conservation under the Basic Act of Environment Policy. The analysis on the foreign system and planning system is available in several thesis and reports available, but they were superficially introducing the planning system that there is a limit to learn in details as to how to respond to the environmental issues in establishing the various spatial development plan. In order to overcome these limitations, it is deemed to require the exchange of opinions with the overseas experts. In particular, there are studies that introduced the spatial development plan and the environment plan of the foreign countries, but it was difficult to find a study that handled the background of why two plans were to be linked or whether the intended objective was achieved or what effect was to reach after the linkage.

For the cases of preparing the biotop mapping, for Korea, there are a few cities such as Seoul City, Seongnam City and others, and for the cases of the foreign countries, most data presented the case of Germany. By reviewing them, they handle how the biotop mapping was prepared or how the biotop mapping resulted as the work undertaken, but the studies lacked how it was utilized in the actual environment plan or how it was used in the spatial development plan. Accordingly, it was difficult to obtain the information on why biotop mapping was needed in the environment plan and how the information is to be utilized. Therefore, there is a shortage of data mentioning on what problems may occur when the actual planning establishment is applied or what basis has to be secured in the system.

2. PROBLEM AND LIMITS OF LINKING PLANNING SYSTEM

2.1 Analysis of Current Planning System

2.1.1 Analysis of Spatial Development Planning System

Now, let's take a look at how spatial development plan is disconnected to the environmental planning system in the substantive aspect and the systematic aspect. First, in the substantive aspect, spatial development plan system has substantially higher linkage possibility with the environment plan due to the several systematic devices specified on spatial development plan laws, however, it still has significant limitations. In the aspect of the system, spatial development plan system does not have the clear establishment of the position of the upper and lower plans to present substantial environment-friendly plan.

In the new spatial development planning system including the Basic Act on National Land and other spatial development plan laws, several measures are introduced to secure the environmental characteristics in spatial development plan. In the basic data survey item, the starting point of planning establishment, several items on environment conservation are included, and in establishing the metropolitan urban planning and Urban Comprehensive Planning establishment, the environment conservation plan and scenic planning are to establish, while the environmental review shall be made in establishing the Urban Management Plan. And for the comprehensive evaluation on development and preservation value of land is made at the time of planning establishment, the Land Appropriateness Evaluation System is introduced to seek the appropriate use of land resources.

Such a systematic effort is a case of showing that the new system is one step advanced in the aspect of strengthening environment feature of the plan than the previous system, and if appropriately established, it is expected to bring substantial result (Sung 1996). However, in spite of such a possibility, the new system has the following short-comings to secure the environmental characteristics in spatial development plan. First, in the aspect of basic data survey aspect, the new system includes the natural environment, park·green area, environment management category, but the survey category is vast with no consistent standard to survey each category that it is highly likely to be a formal survey only. Second, the environment conservation plan and the scenic planning that are required to prepare at the time of establishing metropolitan urban planning and Urban Comprehensive Plan have no tools of planning establishment (basic information) to be only the formal field plan. Third, on the area to establish the Urban Management Plan, the environment review is separately prepared to have the effect of Urban Management Plan on environment resolved or reduced, but the detailed implementation plan is still insufficient. Forth, the Land Appropriateness Evaluation has the limit in difficulty to reflect the ecological feature of the land due to the insufficient natural ecology related data and the development aptitude oriented approach method.

Next is the aspect of system. First, spatial development plan system lacks the position in between the upper and lower plans to have the vertical relativity deficient, and there are many cases that the environment-friendly objective of the upper plan does not solidify in the lower plan. Under spatial development plan system comprised of National Territorial Spatial development plan, comprehensive provincial plan, Urban Comprehensive Plan, and Urban Management Plan (district unit plan), the basic direction on the environment conservation of the National Territorial Spatial development plan is not solidified in the Urban Comprehensive Plan or Management Plan (MOE 2001b).

The second problem of the system is that the status of spatial development plan was not securely established that there is no way of controlling the various development project made up based on each individual law. When a large scale development project is undertaken, it is frequently a case of pursuing the policy without any relativity with the existing plan while the role as the practical plan of spatial development plan more difficult. In addition, the Special Act was enacted with the development principle as the philosophy that the consideration on the environment conservation difficult from the on set with the various special rules including special case of the environment impact evaluation and others. And, the development-oriented Special Act would cause a confusion of planning 위계 by having the Special Act taking the advanced position over spatial development plan and Management Act, the superior law. As the result, the details of urban planning would not have to be considered in the actual development project plan that it cause the reason not to promote the urban development systematically.

2.1.2 Analysis of Environmental Planning System

Next is to look into the substantive aspect and systematic aspect on how the environment plan is disconnected with spatial development plan system.

First, in the substantive aspect, the followings may be pointed out. First, the subject of natural environment conservation treated in the current environment plan is limited to the areas that have an environmental value. Namely, the National Environment Conservation Plans for the project of managing the ecology preservation area for the protection of certain wild life and diverse organism, but the details on urban area where the damages to the natural environment due to the various development and restoration and creation of environment are not treated. Second, the current environment plan lacks the practical ways to exercise the influence on the development that is made in the concrete space. However, the long-term comprehensive plan of environment conservation or city and provincial environment conservation plan is structured with the implementation oriented to set the environment standard per each pollution medium and achieve such objectives that it is difficult to make direct reflection on the spatial development plan. Third, the revised Basic Act of Environment Policy specifies on the mutual linkage of spatial development plan and environment plan at the regional level, however, there is no mentioning on details of environment plan that is to be considered in the spatial development plan. Namely, revised laws presented the linkage of the environment plan and the spatial development plan by specifying the consideration

of environment plans including the Comprehensive Environment Conservation Plan while obligating the establishment of environment conservation planning for city, gun and gu unit, however, there is no actual linking point that practically guarantees the linkage of the two plans that it still is in the declaratory stage yet.

Next is the systematic aspect that has the following problems. First, it is expected to have the conflict in the superior issue in between the environment plan and spatial development plan. Namely, the revised Basic Act of Environment Policy defines the consideration of environment plan at the time of establishing the spatial development plan to emphasize the priority of the environment plan, however, spatial development plan laws define that the urban planning is the basis on the plans on the use of land, development and preservation of land by other laws that these two plans are expected to have the conflict in priority. This is caused by having the device to adjust in the event it is conflicting with the plans under other law since the position of the environment plan and relationship with other plan are not defined in detail. Second, there is a limit in the environmental mapping. The environmental map that is drafted as a part of the environment plan is produced by the entire national land, and if the detail is utilized when establishing the spatial development plan, the environmental map may function as the way to link the environment plan and spatial development plan. However, the current green land nature and the ecological nature and others do not contain the information on ecology in general that it is inappropriate to manage or evaluate the ecology of urban area that its functions are not properly undertaken.

2.2 Problems following the Disconnection of Spatial Development Plan and Environment Plan

The phenomenon appearing from not mutually linked by spatial development plan and environment plan is not difficult to clearly define since there was no experience of linking the two plans. However, if the two plans are connected, there are a few problems that are caused from the current planning system may be resolved.

First, there is no detailed device to control to consider the environment during the establishment stage of the spatial development plan to have the disharmony in scenery or the damages to the natural environment (Choi 2001). Considering the environment at the current planning stage is to review the environmental characteristics in the advance review of the environment and the process of establishing the urban planning. The advance environment review is to establish with the plan that considers the impact on the environment with the appropriateness of location, feasibility of the size and the harmony with the surrounding environment, however, the practical effect is not resulted by not able to involve in the establishment process of such a spatial development plan. The advance environment review a limit in preparing the fundamental alternative because spatial development plan is reviewed after establishing the plan and could not appeal detailed planning contents.

Next, the fundamental problem is that when the spatial development plan is established, there is no information to reflect or determined in the point of view of

environment conservation due to the discontinuity of the plans. Frequently, it is emphasized the importance of environmental conservation in various spatial development plans and has the basis of plan with the ecological consequences and connectivity to the green area of the subject area, but such matters are actually not injected in the actual planning contents since there is no information required in the establishment stage of the spatial development plan. The reason that the analysis of the subject site for the development possible area is that there is no information to be referred to in the spatial development plan.

These problems are the causes to consequently decline the appropriateness for spatial development plan and the environment policy, and frequently it causes the conflict. The conflicting problems in the spatial development plan and the environmental policies are shown in many areas such as the conflict surrounding the development and preservation in the area with the high ecological value, conflict of standard of highly dense urban development and environment, conflict on urban growth and the pollution management in environment and others. In the rural areas, there are many development project following the pressure of development that the natural environment has been damaged to result in losing the environment policy. In the city areas, the demand of highly dense development collided with the environment policy for protecting the clean living environment. The new city spatial development plan in the suburban area brought the increase of commuting traffic volume to increase the atmospheric pollution and the energy consumption. For the demand of leisure spaces, the artificial tour site development in the areas of high preservation value brought the problems such as the fragmentation of ecosystem.

2.3 Needs of Linking Spatial Development Plan and Environmental Plan

Spatial development plan and the environment plan have a common point in the aspect of they define the human activities that shares the certain land ultimately. In fact, development and conservation are like the both sides of a coin that the problem of how to develop is, conversely speaking, a matter of how to preserve. Accordingly, spatial development plan that reflects the demand for development in the national land is closely related to the environment plan that is established to improve and preserve the national land environment.

However, spatial development plan and the environment plan are established by different subject and strive for different objective that they have high possibility of conflict in planning details. As mentioned earlier, spatial development plan has actually brought many problems following the lack of consistency with the environment policies. On the conflict of the two plans, there are several problems arising such as rampant development in the national land and so forth. Accordingly, if the two plans are appropriately linked, the use and development of environment-friendly national land that the society demands and the environment policy will sustain close relationship with our actual life. By linking the two plans to maintain the mutually supplementary relationship, the conflicting relationship may be resolved.

The new spatial development plan related system that is pursued has equipped with several systematic devices to secure the environmental characteristics. Following the newly revised environment related system, the linking of the planning system at the time the environment plan is established would resolve a significant portion of problems to maintain the amicable relationship. The environment plan lightens the desirable future image of the natural environment, and helps to capture the problems in detail when there is a conflict surrounding development and conservation. Namely, it exceeds the level of pointing out the damages to the natural environment following the implementation of spatial development plan, it may clarify the problem even more by pointing out what is the friction point with the environment plan based on the ecologic value of the natural environment.

3. REVIEW OF FOREIGN CASES AND CURRENT ISSUES

3.1 Germany

Germany has been preparing the system based on the landscape ecological concept when it establishes the spatial development plan with the emergency of the point of view to treat the land use in landscape ecological point (Thüringen 1993). Pursuant to the Federal Nature Protection Act that was fully amended and supplemented in 1976, the nature protecting plan that has the look of a partial plan was integrated with the scenic management plan that considered the aesthetic and social aspects to prepare the ‘Landschaftplanung’ (Thüringen 1993). In addition, the ‘Eingriffsregulung (Eingriffsregulung)’ has been working as the regulation to mandate the practical linkage of the spatial development plan and the environment plan, and has been working as the role to link the spatial development plan with the ‘biotop mapping’ enabling the space availability in the environment plan (Ministerium für Umwelt, Natur und Forsten des Landes Schleswig-Holstein 1999). The Federal Nature Protection Act guarantees the linkage of planning system by considering the Landschaftplanung for establishment in response to spatial development plan per spatial rank and consider it in spatial development plan (Riedel and Lange 2001). Landschaftplanung (Senatsverwaltung für Stadtentwicklung und Umwelt-schutz. 1994a) is established in state, region and local unit in the scenic ecology program, basic plan of scenic ecology, landscape ecological plan, green land clearing plan and others to reflect for state spatial development plan, regional plan, land use planning, district detailed plan and others. It also specifies that the plans based on mutually different laws such as the Federal Nature Protection Act (Bundesnaurschutzgesezt), state nature protection laws, Federal National Land Construction and Planning Act (Bau- und Raumordnungsgesezt, BAUROG), construction laws (Baugeseztbuch) shall reflect and utilize (Umweltbundesamt Berlin 1995).

The Eingriffsregulung' specified under the Federal Nature Protection Act and nature protection laws of each state prohibit or minimize the interference of natural environment following the development to present the directions of spatial development plan and Landschaftplanung (Riedel and Lange 2001). According to

this regulation, in the event that a development project proves the essential elements involving the nature interfering action, the permit may be granted only if the correction after the interference action is possible, or any part of the project has special implication to have the priority over the interests of nature and scenery. And, it defines to minimize or make restoration appropriately to the regional characteristics for the interference on natural environment and scenery (Riedel and Lange 2001, Stadt Eckernföde 1991).

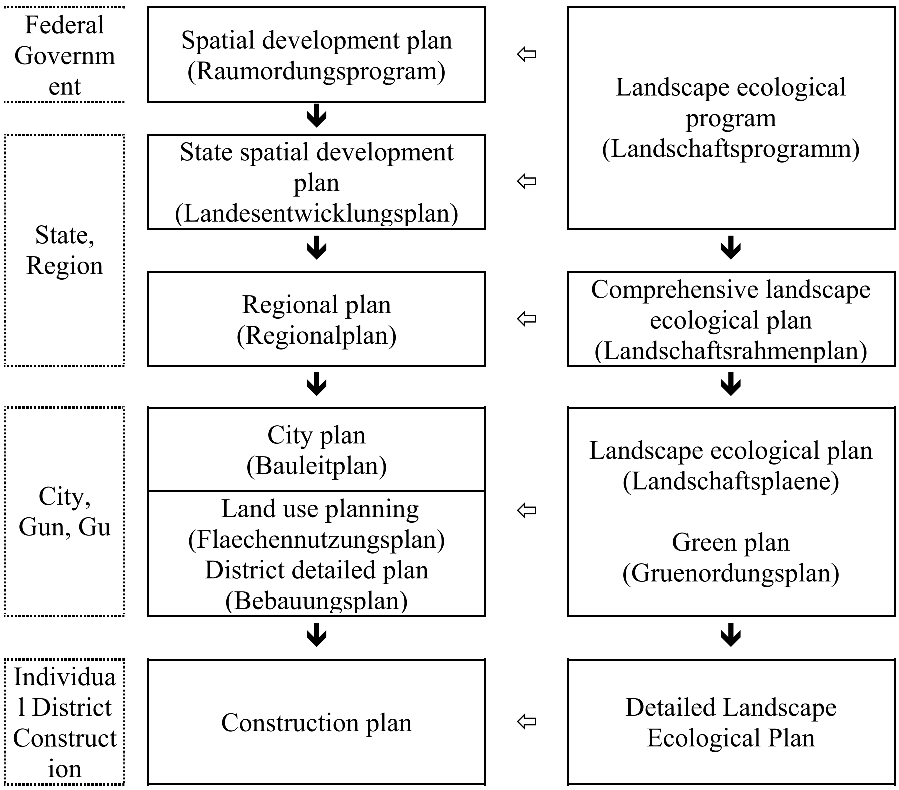

Figure 1. The Spatial development plan and the Linkage of Landschaftplanung in Germany

In order to reflect the environment plan into the spatial development plan, the basic information related to the environment is made in biotop mapping and utilize it as the basic data for both plans (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie 1999). The biotop mapping is a way to use the land on the landscape ecological point of view after surveying the ecological characteristics of the subject site for planning and assess in certain standard. Not only that, it displays the environment plan by applying in concrete space to refer to it at the time of establishing the spatial development plan. Namely, the biotop mapping has become

the basis of not only in the land use information but also the basis that guarantees the ecologic use of land including the ecological information of land (Thüringen 1999).

On the outside, the biotop mapping makes the Landschaftplanung for space to take the basic role to enable the linkage of land use planning, however, the link of the actual connection is the sufficient "consultation" between the two fields (Senatsverwaltung für Stadtentwicklung, Umwelt-schutz und Technologie 1999). Namely, the main bodies of the two plans discuss and gather the opinions of local residents, perform the basic survey together, and go through the process to sufficiently consult to the conflicting issues to reflect the contents of Landschaftplanung in the spatial development plan.

For the linkage of spatial development plan and environment plan, there are active consultation process between the main bodies of the two plans to have the compromise surrounding the preservation and the development of land in concrete terms. The vertical linkage of the planning inside is defined under the law to have the plans consistently established for each spatial level of plans (Thüringen 1999).

Germany that has been promoting the linkage of spatial development plan and the environment plan (Landschaftplanung) system (Umweltbundesamt Berlin 1995, 1997) is known to enjoy the successful result on nature preservation and environment protection by considering the environmental damage and its impact caused by land use and development. In addition, with the turnaround on the problems following development, the right development that considers nature is attracted. Namely, Landschaftplanung does not work as a way not to make a development but is thought of nature as to inducing the right development (Umweltbundesamt Berlin 1997).

3.2 Japan

Japan does not have the systematic environmental planning system that responds to spatial development plan system (Ministry of Environment 2000b). Of course, Japan has implementing various policies and various policy developments for structuring sustainable national land·city. However such a policy is mostly made by the voluntary efforts of the Ministry of Land and Transportation (Ministry of Construction 1994), the main department in charge of spatial development plan that there is no systematic cooperation or link with the Ministry of Environment.

In the national land transportation, the environment policy outline, green land generation policy outline are established and the urban environment plan, basic plan for green land and others are established to have environment conservation as the internal objective in the construction administration. The urban environment plan is established in the applicable administrative village for promoting the environment policy outline determined by the basic direction of the environment policy and contains the measures to utilize in the environment planning of the urban planning. In the basic plan of green land, it determines the matters on the green land conservation in the green land conservation district, the objective of green land following the policy outline (Ministry of Construction 1994).

However, the objective and ideals of the Urban Planning Act is defined to "secure the healthy and cultural urban life and functional urban activities" to "seek the reasonable use of land" that it does not contain the environment-friendly concepts. In Japan, the linkage of spatial development plan and the environment plan may be said to pursue the environment-friendly on the basis of testing project, individual project and individual plan rather than the linkage of the systematic planning (Ministry of Environment 2000b, Ministry of Construction 1994).

The administrative measure of voluntary level is on progress in the form to have the comprehensiveness or relativity with the existing urban planning that overseas the city for the projects and planning. For a representative business, there are environment model city promotion project, environment housing city model project, environment housing construction promotion business and others.

3.3 The Netherlands

The Netherlands (Bennett 1991, Bouwer 1994, European Commission 1999, Miller and de Roo 1996, 1997) is equipped with the environmental planning system that is responded to spatial development plan system that it is prepared with the basic condition to consider in times of establishing spatial development plan, however, it does not mandate the linkage of the two plans in the system. From the later part of 1980s, there was a need of linking for the two plans and began the attempt of linkage from the national unit. In the spatial development planning of national unit, the space and environment related fields (it largely means 4 fields including space, environment, nature and water) are basically considered to establish the plan. Each of the space and environment related fields began to participate or involve in the plans of other field (VROM 1999, 2001a, 2001b).

However, the lower stage of the structure plan and the land use planning is established in the department of the applicable local government with the mutual consultation with the pertinent department, but it was not property made in reality (Straaten 1992). When the linkage is not made well in the local unit that established spatial development plan that brings the change of space, the Netherlands promoted the pilot project and attempted the integration in between the regional level of plans. Namely, in order to have the environment policy applied to meet the various regional realities and obtain the agreement of various relevant parties of on site where the policy is enforced, and there is recognition of needing the area-specific approach, and an attempt is made for integration between the plan in the regional and local level (Zonneveld 2000).

In the regional level, the ROM (Ruimtelijke Ordening en Milieubeheer; spatial development planning and environment) project was promoted in an attempt to integrate between plans while the local level had the urban·environment (Stad and Milieu; City and Environment) project to attempt for cooperation between plans (Miller and de Roo 1999, VROM 1999). And, as a way to link effectively for spatial development plan and environment plan, several indices are developed and used. Amsterdam City developed and applied the environmental indices that might be applied in the city level, such as the city bubble and the environmental matrix to

enhance the environmental features of spatial development plan (Miller and de Roo 1997).

Through the ROM project that was pursued to the subject of 10 pilot regions, the local governments in the region and the private business enter into the agreement to establish one integrated plan. This plan thoroughly considers the environmental aspect to pursue the integration with the environment plan. Namely, the environment improvement and improvement policy is integrated from the regional level to the spatial development planning system. In the meantime, the urban and environment project promoted for 25 model cities granted the flexibility in the application of the environment standard to the cities with severe environmental pollution, it attempted to resolve the conflict of spatial development plan and environment plan.

3.4 Other Countries

The Great Britain, France, Sweden and others (Berry and Mcgreal 1995, Centre for Environment and Planning 2000, European Commission 1999, 2000a, 2000b, Lemons 1995) do not have separate environment plan system responding to spatial development plan system, but they have the national level of environment plan or environment objective only. Accordingly, they promote the linkage of substance in spatial development plan for the pursuit of environment rather than seeking the linkage of the planning system. For the substantive linkage of spatial development plan and the environment policy, they have their own systems.

First, the Great Britain (European Commission 2000b) mandates to reflect the objective of the environment policy when establishing spatial development plan through the instruction of the National Planning Policy Guidance Notes (PPG) and Regional Planning Guidance (RPG). Through the 27 items of PPG for each field and RPG of each region including London, the southeast and southwest areas, and the Thames River area, it promotes to have the spatial development plan within the scope not to violate the national objective in natural environment and preservation of scenery.

France (European Commission 2000a) also seeks the substantive linkage between the plans through providing the consultation frame between the planning bodies and providing the instruction on the spatial development plan. Namely, through DIA (d'Amenagement Territoriales Directive), it provides the instruction for natural and environmental protection, and through DATAR (Delegation a l'Amenagement du Territoire et a l'Action Regionale; Inter-ministerial Regional Planning Agency), it helps to progress with the consultation between the departments at the time of establishing spatial development plan.

The systematic linkage between spatial development plan and the environment plan is not that great in Sweden (European Commission 2000b, Lemon 1995) but it guarantees the environmental friendliness of spatial development plan by using the supervisory authority of administrative system and the instruction of the country. The Swedish environmental objective and the space policy statement perform the instructive role for strengthening the environment of spatial development plan, and

induce spatial development plan to establish environment friendly policy through the administrative supervision and the environment court.

3.5 Comparing the System of Planning of Each Country and Current Issues

For the needs of linking the spatial development plan and the environment plan, almost all countries shall the same senses. However, following the difference of planning establishment condition including the substantiation of environmental objective in the spatial development plan and the separation of environment plan system, it may be said to contrast with the method to pursue the linkage or integration of planning system and the method to pursue the substantive linkage.

Germany is the place that has the best linkage of the planning systems. It has the landscape ecological planning system that is different from the spatial development planning system, and through the space of the environment plan, it selects the method to mandate the linkage of the two planning systems in the system. On the other hand, the Great Britain, France, Sweden and Japan do not have the environmental planning system that responds to the spatial development planning system, however, since the objective of environment policy showed the tendency of substantiating in the spatial development planning that it pursues the substantive linkage of the plans. The Netherlands, like Germany, is equipped with the environmental planning system, but it lacks the systematic device to mandate the linkage between the two plans yet. And through the establishment of integration plan that merged the two plans in the regional level with the subject of pilot area selected by the central government, it is in the transition stage to seek the possibility of planning linkage.

In spite of the differences in such a linkage method, the cases of each country show what are the common necessary matters needed for the linkage of the plans. Namely, it is known that the system and custom that confers between the main bodies of the spatial development plan and the environment plan are the important factors of planning linkage. The Netherlands, the Great Britain, France and others have the department related to spatial development planning and the department related to environment integrated to have the natural meeting of the exchange or conference between the two main bodies of the plans. Germany does not have the department integration but it has a system for the main bodies of the two plans to frequently meet and adjust the opinions (Ministerium für Umwelt, Natur und Forsten des Landes Schleswig-Holstein 1999). In addition, it shows the need of having the ways to make space for environment information in order to apply the environment policy in the detailed areas while reflecting the environmental objective in the spatial development plan.

4. BASIC ISSUES AND PREMISES FOR LINKING PLANNING SYSTEM

4.1 Tasks to Promote

4.1.1 Point of View of Spatial Development Plan

The tasks to resolve for the linkage of spatial development plan and the environment plan system can be divided into the point of view on spatial development plan and the environment plan. First, the current issue in the point of spatial development plan, it may be arranged in the following 4 types.

First, the issue of environmental damage following development shall be included in the environment conservation field of spatial development plan. In the environment conservation field of spatial development plan, the matters on environmental damage and fragmentation of ecosystem are made, and on such a foundation, the matters related to development such as the land use planning or traffic planning are prepared. If the environment conservation field has the relativity with the plans of other part like the land use planning, the details of each field of spatial development plan may maintain the mutually supplementary condition.

Second, it is the strengthening of relativity of environment conservation field plan between the upper and lower plans. Namely, in spatial development plan such as National Territorial Development Plan, Comprehensive Provincial Pan, Urban plan and others, the details of environment conservation field of upper plan are reflected in the environment conservation field of lower plan. If the contents of environment conservation planning of upper and lower parts are consistently established and reflected, and seek the concrete practice means to the lower plan, each stage of spatial development plan may secure the mutual relativity naturally.

Third is the linkage structure in between the plans of each field. Namely, the mutual relationship between the plans of each field of spatial development plan such as the land use planning, traffic planning, facilities planning, park and green planning, environment conservation planning and others are established with the environment conservation as the basis. To support it, the key is to secure the basic information related to the ecology including the land and plants and others that may display the impact on the environment at the time of establishing the land use planning. Based on this, the land use planning will turn to the work to seek the subject for preservation of ecological value, not the analysis of condition to seek the development site. Once the environment plan is first established to structure the system to link to spatial development plan, the land use planning would accept the analysis of the environment plan and establish the land use planning.

Forth, there has to be a change of thought on the recovery and plan of ranking in between the upper plan and the lower plan. Namely, spatial development plan shall have the rank in between the upper and lower plans and there is a need of change of attitude to face the planning establishment. For example, the development project performed by the individual law is the upper plan that frequently does not reflect the Urban Comprehensive Plan into the planning detail, and this shall have the position as the upper plan by preparing the device to go through the consultation process or reflect the details of planning details. In addition, there is a demand of converting

the concept that values more for the growth than the environment conservation that treats the damages to the natural environment insignificant. Such a change of awareness involves the value point of person planning that it is not easily resolved for force it. Accordingly, when establishing the plan, if the environment conservation expert is participated or the plan is established on the basis of the basic information, it may bring the balance of development and preservation. If there is a device to link the environment plan with spatial development plan, it may be possible to establish spatial development plan based on much more balanced environment conservation.

4.1.2 Point of View of Environment Plan

Under the point of view of environment plan, the primary task to resolve for linking with spatial development plan shall be cleared in the following two cases.

First, it is to structure the environmental planning system that takes the mutually supplementary role in responding to spatial development plan. The 「National Territorial Development Plan-Comprehensive Provincial Plan-Urban plan」 system of spatial development plan shall be made consistent with the environment plan system and the administrative zoning unit of the 「national land and metropolitan city」 to have the rationality. For this purpose, there is a need of establishing the environment conservation plan of city, gun and gu unit to harmonize the development and the preservation as well as to prevent in advance for the environment pollution and the environment damaged at the regional level. In addition, in order to have the mutually supplementary relationship for spatial development plan and the environment plan system, the details of the environment plan shall be converted from the policy-oriented to the practice plan. In addition, as in spatial development plan, there is a need to prepare the practical connection through the spatial development plan of the environment plan.

Second, it is to structure the basic information for establishing environment plan. The basic data for environment that can be reasonably reflected in spatial development plan field is insufficient. There is a need of various maps to consider the environment in detail. The factors that impact on environment such as soil, climate, organism, habitat, water, atmosphere and flow of substance by the human development shall be made in drawing. In particular, the biotop mapping that contained the habitats for all organisms and the ecological characteristics are the basic information that must be produced for the linkage of spatial development plan and environment plan.

4.2 Fundamental Premises

4.2.1 Alternatives for Linkage

Setting of Alternative of Linking spatial development plan and Environmental Planning System

The linkage of planning system is reviewed for the following 3 types (Choi 2001) by considering the realistically possible Alternative and idealistic but to be pursued Alternative and others.

1) Alternative 1: Plan to seek various ways for environment conservation in spatial development plan
2) Alternative 2: Plan to establish a separate environment plan that can be reflected in spatial development plan
3) Alternative 3: Plan to fully integrate in one planned frame for spatial development plan and the environment conservation plan

Alternative 1 is to strengthen the environment feature in spatial development plan that, rather than the direct linkage with the environment plan, it is a plan to seek the plan to reduce on the scene following the development and the damage in the natural environment. Alternative 2 is the alternative to reflect the environment plan at the time of establishing spatial development plan for each stage in order for the practical environment conservation. For this purpose, separate environment plan is to be established for each administrative unit and must consider at the time of establishing the spatial development plan. Alternative 3 is a plan to integrate spatial development plan and the environment plan by having development and environment conservation as one policy objective.

First, in the point of view of relativity with the planning system, Alternative 1 has no relativity of the two planning systems, but the environment features are strengthen in spatial development plan to have the practical effect through the two planning system linkages. The linkage between the plans through the establishment of environment plan of Alternative 2 is the core alternative that is pursued in this study. Alternative 1 has no guideline that may consider the environment conservation in spatial development plan that the consideration on the current environment may be slightly insufficient, on the other hand, Alternative 2 prepares the various system to secure the relativity between the two plans and arranges the environment plan system to link to spatial development plan system that the relativity between the plans may significantly be heightened. Alternative 3 is an alternative that asserts the integrated planning system as a new frame rather than the linkage of the planning system.

Looking from the point of view of possible promotion, Alternative 1 and Alternative 2 are the alternatives that can clearly be promoted under the current system. The important thing in Alternative 1 and Alternative 2 is on how much the basic information related to the environment is structured. If the space for environment data that is the basis of establishing the environment plan is not available, the detains of the environment plan that may be reflected in spatial development plan would be extremely limited. Alternative 3 is ideal, but under the current planning system and administrative organization, it is almost impossible

plan. And this alternative would be unrealistic when considering the fact that it is possible only when there is a new recognition on planning and land together with the new system and new organization.

As the result of comparing the 3 Alternatives, and when considering that Alternative 3 is an alternative realistically not promoted, Alternative 1 and Alternative 2 are effective alternatives. Considering the condition to prepare spatial development plan to this point, Alternative 1 may help partially on the establishment of the environment-friendly plan, however, considering the impact of environmental damage while establishing spatial development plan would be difficult task. Considering such a point, Alternative 1 is a prerequisite for Alternative 2 that it would be desirable to pursue together with Alternative 2.

Basic Principle of Linking Planning System

For the linkage of spatial development plan and environmental planning system, first, the establishment of direction on the priority of planning, second, the linkage of the planning system, are first determined. The direction on the scope to think of it from the current planning frame or commence on the basic matters including the planning frame as well as the degree and method of linkage and others will have to be determined.

The big obstacle in the linkage of spatial development plan and environmental planning system is the issue of priority to have which plan to have the priority. Looking into the plan as with the purpose to link, it is appropriate to have the details of the environment plan first prepared and it is reflected in spatial development plan. The issue is on can the priority of planning be secured even if it is first established, and whether the reflection of plan content is desirable to force unilaterally on one side. Here, the two plans shall be linked in mutually supplementary relationship in the point that the environment plan is a spatial unit of the existing spatial development plan. Accordingly, the linkage of the two planning systems shall follow the mutually supplementary principle.

Second is the problem of which plan frame begins the linkage. Linking of the two plans means the revolution of the planning system in fact. Perhaps there may be an argument to change the frame of planning in complete sense. However, in order to change the frame of plan completely, the related system as well as the frame of the organization shall be fully revised. This method means the integration of two plans in one as in the previously reviewed Alternative 3. Accordingly, the linkage of the planning system is reviewed within the acceptable scope under the current system and has to have the precondition of improvement in the necessary system and planning frame with the will of reform and turning around of ideals.

Last is the basic direction on the issue of how much it has to be handled on the linkage of the planning system. The linkage of the actual planning system is not something that can be pursued immediately. It would be possible to have the clearing of relevant system and accumulation of basic information to realize it. In addition, the research on the planning system linkage will have to be accumulated to present the social sympathy, desirable direction and the detailed plan. This study is attempted for the first time that its implication may be found in presenting the need

of linkage and direction. However, the scope of linkage is set to present the position of researcher on the ways and means of linkage under the point of view to present the tasks for the future study.

4.3 Basic Works for Linking Planning System

4.3.1 Strengthening of Environmental Characteristics of Spatial Development Plan

Establishment of Spatial Development Plan Considering of Environmental Damage Issue

The reason for not appropriately handling the damage of environment in spatial development plan is that the analysis in the plan establishing process can be determined only for the development possible area. It is followed by raising the vulnerability in the environmental planning within spatial development plan and the weak systematic basis to consider the environment.

Accordingly, when spatial development plan is established, there is a need to supplement the planning establishment process to consider the ecological characteristics of land in the condition analysis for the consideration of the environmental damage issue. Based on it, the planning details of environmental preservation that includes the damages to the environment in each planning shall be the basic direction to pursue.

In order to consider the ecological characteristics of land in times of spatial development plan, it is important to use the analysis to be utilized as the basis to consider the environment before the development. This can be done not for the formal and decision for development possible land, but to formulate the characteristics as the land ecology to make it as the space with the value to protect and form the green land formation. For this purpose, there is a need of system for verification of basic information utilization and the inspection stage on planning contents with the analyzed drawing in early after preparing and establishing the plan for making the change of survey analysis item, drawing of analyzed matters, and contents of condition analysis to become the basis on all planning field.

For such a plan, there are ways to evaluate including the analysis details, degree of consideration and others in the environment review or advance environment review. In addition, it is deemed to be fine to utilize the biotop mapping under the analysis to consider the ecological characteristics of land. The biotop mapping is mainly utilized in the environment plan, but it may be utilized in the analysis on spatial development plan. For this purpose, there is a need of two planning related experts to participate in preparing of the biotop mapping. Including the environmental management issue of the spatial development plan on the National Territorial Spatial development plan stage would have its own limit, but the clear basic policy for reducing the damages to the natural environment may need to present.

In establishing spatial development plan, the planning content of the environment conservation field that included the environmental damage in the planning of each

field is taken as the basic plan. For this purpose, the details of environment conservation planning shall be included in the planning of each field including the land use planning, traffic planning, park and green planning. And the plan shall be prepared by considering the environment conservation plan to prepare by the ecological analysis. In addition, it is needed to evaluate the independent review on environment and review on advance environmental issues on planning of it in various planning field. In order to establish the plan in such a way, there are change of planning establishment technique, change of special field to participate in the plan, structure of cooperative system and conversion of recognition to first consider the environment.

Environmental Consideration in the Process and Evaluation of Planning Establishment

In order to consider the environment in the planning establishment process and evaluation, it is important to follow the index and matters related to environment that the upper plan proposes. In addition, the environment review process that is implemented in the urban planning establishment stage shall be strengthened.

Following the environment index of upper plan in the planning establishment stage is to present the environment index on the basis of the planning establishment before preparing the urban planning, urban development project planning and others. In such a way, it is possible to promote to prepare the environment-friendly plans voluntarily in all fields of spatial development plan to keep the environment index. The environment index may be one or present for several. In order to use the environment index in the planning establishment, the various surveys have to be taken to make the decision of index category and the planning standard for each index category.

In order to strengthen the independent review process of the environment that is implemented under the planning establishment stage, the detail for independent environment review is supplemented to evaluate the practical planning details, process and the like, and needs to make the basic survey analysis in the review of environment. In addition, the plan is sought to replace the urban planing with the independent review on environment assessment when reviewing the advance environment review for the plan that passed the independent environment review.

Consideration of Landscape Ecological Characteristics at the Spatial Development Plan

In order to consider the ecological characteristics in the use and facility classification for the urban planning, the ecological element is considered in the use area classification and makes the condition to designate. In addition, the classification of the urban planning facility is diversified to plan for the urban space where men and nature co-exist.

In order to consider the ecological characteristics of landscape ecology from the use area designation, it is needed to have the procedure to designate the use area by structuring the basic information on the land ecology. The types of use area may be diversified. By securing the necessary land for the convenience of human and the

maintenance of natural environment, and for inducing the planned use, it shall make the designation of various uses, including the designation of mixed use or special use, possible. For example, there are public site for necessary facilities for civic life, site to install key facility or environment base facility, site that limits the use in response to the impact on the environment, site needed for water management such as surface water, underground water and others, and site for separating the soil preservation or scenic protection from development.

The classification of urban planning facility has to be diversified to plan it as the urban space to have the co-existence of nature and human. For example, the urban ecology facility is newly established to have the rivers classified from the natural disaster prevention facility to the ecology facility, and the wetland, dormant land and others are included as the urban planning facilities to consider the ecologic elements of the land.

Consideration of Relativity for Each Stage of Spatial development plan

In order to enhance the relativity for each stage of spatial development plan, there is a need to improve the procedure to change by the project planning under the individual laws for the upper plan, spatial development plan. The National Territorial Spatial development plan has the mutual relativity in system for the comprehensive provincial plan, urban planning and others, and the reason to stay in actual formality is that there is no practical ways to solidify the upper plan details in solidifying for the lower plan stage.

For this purpose, the detailed matters to consider the upper plan in spatial development plan laws and establishment of urban planning instruction and the process to inspect have to be presented. Under the existing system related to spatial development plan, the change has been available once the project plan was established under the spatial development planning or urban planning. This would be an action to simplify the administrative procedure under the era when the development had to be made easy, and under the process, there is a tendency of disrespect spatial development plan and the atmosphere to make changes at will under the individual project unit. Under the new spatial development plan system, once a plan is established, the entire land use and development project are made under the system that is not to be changed by individual business. Rather, the development project individually pursued shall be appropriate to the details and characteristics of the upper plan. For this purpose, the lower plan shall consider the upper plan, but the upper plan shall respect the lower plan to establish. Namely, the upper plan and lower plan shall be established under the mutual cross principle.

In the meantime, the current linkage of each planning field and each planning stage is insufficient, but the relativity per each spatial development plan is likely to enhance if the details of environment plan is considered voluntarily for spatial development plan. The requirement of consideration given to environment in each and all land use planning, traffic planning, park and green planning and other plans would be the first step toward the environment-friendly spatial development plan. It would be desirable to make direct link of spatial development plan and the environment plan, but the linkage of the two plans would not be easy since the

relevant departments emphasizing their own unique work undertakings. Considering such a condition, until the system for the linkage of the two plans and the concrete ways to solidify. The two plans are separately made like today, but when spatial development plan is established, the contents of the national environment conservation planning shall be considered.

4.3.2 Structuring of Environmental Planning System

System Structure of Environment Plan

In order to structure the environment planning system, each stage of environment plan shall be fitted to the step of current spatial development planning system, and requires the review of the environmental planning system to fit into the two-stage of the urban planning system.

Fitting of the current spatial development planning system and the environmental planning system is structured with the 「National Environment Conservation Plan - Provincial Environment Conservation Plan–Comprehensive Landscape Ecological Plan」 system for environment plan following the newly revised Basic Act of Environment Policy. Under the environmental planning system, the current urban planning is segregated for 「Urban Comprehensive Plan, Urban Management Plan and District Unit Plan」 and the respective functions are classified that, in order the effectively link spatial development planning system and the environmental planning system, the urban planning may be classified in Landscape Ecological Plan (so called “City·Gun·Gu Environment Conservation Plan”).

Under this study, the linkage of spatial development planning and environmental planning system is structured in 4 stages of “national, provincial, city and gun, and some areas”. In particular, the environmental planning system that may be linked to the urban planning system is classified in two stages. First, the name of environment plan that responds to the urban planning is the “Landscape Ecological Plan”, and the environment plan responding to the Urban Comprehensive Plan is called as Comprehensive Landscape Ecological Plan, and the environment plan that responds to the Urban Management Plan is named as the Landscape Ecological Plan.

In the meantime, in order to resolve the problems of scenic and natural environment conservation through the linkage of the two plans, it is deemed to need the environment plan that supports the District Unit Plan, one of the Urban Management Plans established on some district. In this study, the environment plan that links to the District Unit Plan is called as “Green Plan”. However, the District Unit Plan may be said as not a separate plan unit but is a part of Urban Management Plan.

In spite of that, mentioning separately for the Green Plan in the environment plan responding and the District Unit Plan as the lower planning of spatial development plan is that the District Unit Plan is one that treat the environment in dimension in spatial development plan. Accordingly, mentioning separately of district unit plan as

a spatial development plan stage, it presents the Green Plan as a separate planning stage for an environment plan. In fact, when seeking the systematic means on the two planning system links, there is a need of fundamental review on planning establishment system.

4.3.3 Contents of Environment Conservation Plan

National Environment Conservation Plan

The environment conservation plan for national land is the upper-most plan on the environment conservation field, and undertakes the role to provide the instruction on planning establishment of lower space unit in mutual cooperation with the upper-most plan, the National Territorial Spatial development plan, on the development policy. In addition, it shall have the position to respond and harmonize with the National Territorial Spatial development plan, and it shall mutually be linked to the environment conservation field of National Territorial Spatial development plan. The environment conservation plan shall prevent in all areas for environmental damages and the pollution caused by the administrative planning and development project and undertakes the preventive policy planning to induce and support the environment-friendly development.

Figure 2. System of Environment Plan following the Planning Space Stage

In this planning, the comprehensive and future-oriented policies are presented for the base structure for sustainable national development that environment and development are harmonized and strengthening of the advanced prevention function and environment-friendly national land environment conservation. Accordingly, the major contents of the plan express in descriptive way not the physical expression.

Currently, at the Ministry of Environment, there is a study[ix] for establishing national environment conservation plan.

Provincial Environment Conservation Plan

The provincial environment conservation plan accommodates the details of the upper plan, the national environment conservation plan, and undertakes the role to cooperate with the comprehensive provincial plan, and compose with the policy details considering the characteristics of the applicable region. Accordingly, the provincial environment conservation plan is linked to the environmental preservation field of the comprehensive provincial plan, and it is expressed in descriptive form as in the environment conservation plan.

The provincial environment conservation plan shall present the plan to solidify the national land environment, environment conservation of scientific and systematic national land, national land environment conservation to prevent in advance, ecology-oriented national land environment conservation, national land environment conservation considering the regional characteristics, and the national land environment conservation for policies on the basis of participation and cooperation. In addition, the environment index of the applicable province is established, and structures the major preservation axis and ecology network through the environment survey and structuring of information network, and present the preservation and restoration plans of major natural ecology.

Comprehensive Landscape Ecological Plan

The basic plan for scenic ecology shall take the role of environment planning that is mutually connected to the Urban Comprehensive Plan while accommodating the details of the upper plan, the national environment conservation plan and the provincial environment conservation plan. The details of the basic plan of scenic ecology expressed the descriptive expression and in drawing to make the spatial development plan and it are linked to the land use planning of the Urban Comprehensive Plan, environment conservation planning, park and green planning. Namely, by surveying, evaluating, and analysing the ecology status of the applicable city in the basic plan of the scenic ecology, the ecology status chart is prepared, and this is utilized as the background in establishing the land use planning, environment conservation planning, park-green planning of the Urban Comprehensive Plan.

In the basic plan of scenic ecology, it shall include the preservation of the outstanding ecology as well as the contents related to the recovery of the damaged ecology, and the ecology network is structured on the basis of ecology survey result of the applicable city. Here, it shall reflect the preservation axis and ecology network structured in the upper plan.

Landscape Ecological Plan

The landscape ecological plan responding to the Urban Management Plan requires the presentation of environment plan objective and improvement direction with the comprehensive natural environment and the protection of scene of entire city. In

light of the objective of landscape ecological plan, the major details of the plan is handled with focus on objective establishment and improvement plan including the nature circulation system and restoration, protection and management of biotop and organism, scenic protection and management, resort and green area use and the like. The result of the landscape ecological plan prepared on the basis of such details reflects obligatorily in deciding the use area, zone, district under the land use planning.

Green Plan

The green planning responding to the district unit plan shall accommodate the objective and improvement direction of the basic plan for scenic ecology or landscape ecological plan in detail and the spatial development planning is to make as the final planning stage to establish as the environment friendly stage. The green planning is established in each planning part within the district unit plan or simultaneously with the district unit plan rather than separately establishing the district unit plan, and it shall be established through the biotop survey and assessment. Under the green planning, in order to realize the objective of nature protection and scenic management, the requirement of the applicable area and the alternative are expressed in report and drawing, and the drawing preparation of the green planning shall be prepared for status chart and the planning chart[x] to utilize in the district unit plan.

5. TOOLS AND METHODS FOR LINKING SPATIAL DEVELOPMENT PLAN AND ENVIRONMENTAL PLANNING SYSTEM

5.1 Linking Method of spatial development plan and Environmental Planning System

5.1.1 Linking for Each Planning Grade

It is feasible to link in meeting with the environmental planning system based on spatial development plan system established with the planning system for planned spatial unit.

First, at the national land unit, the linkage is made for the National Territorial Development Plan and the National Environment Conservation Plan, at the provincial unit, the Comprehensive Provincial Plan and the Provincial Environment Conservation Plan, at the city·gun unit, the Urban Comprehensive Plan and the Comprehensive Landscape Ecological Plan, Urban Management Plan for Landscape Ecological Plan, and at the district unit for District Unit Plan and Green Plan. The Green Plan is established with the partial plan of district unit plan, but the participation and consultation of environment plan expert shall be guaranteed.

5.1.2 Linking of Planning Process

The linkage of planning system shall be made comprehensively in the survey, evaluation, and planning process, and if the planning content to be linked is not solidified in system, it will be simply the formal slogan. In order to link the two planning systems in the survey stage, the integrated survey system shall be prepared to share the spatial development planning and the environment plan. The integrated survey plan shall be established to utilize in the environment management by comprehensively adjusting the various basic survey sporadically made by the need of each field of natural environment, living environment, and national land environment. In order to overcome the limit of duplicated survey of spatial development planning and environment plan, the survey items common to the 3-part, national unit, city·province unit, city-gun-gu unit, are cleared to implement the joint survey and share the survey result. In addition, the survey result shall be made

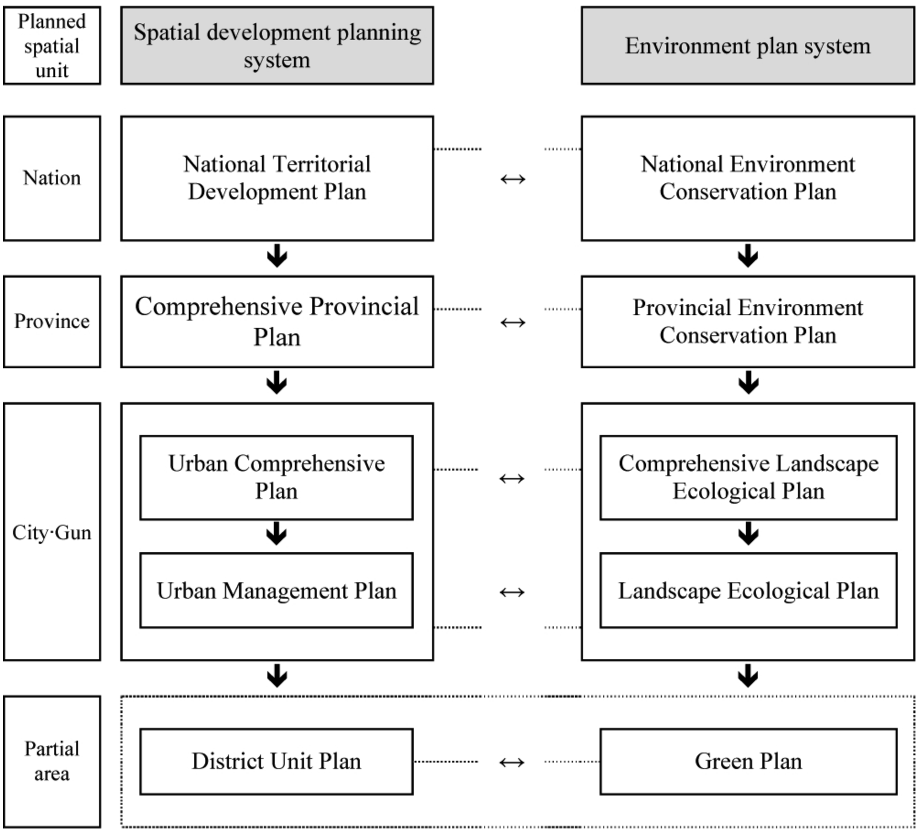

Figure 3. Linking of the spatial development plan and the environment plan for sustainable development

in drawing to utilize in the environment plan, and seek the system to share in many fields, and administrative departments and central-regional governments to use the common information at any time.

In the stage to evaluate the land based on the survey data, the spatial development planning and the environment plan are structured with the joint evaluation system and the evaluation result is prepared with the environmental mapping to utilize as the basic information of the two plans.

The land environment evaluation of the environment plan and the land aptitude assessment of spatial development planning have similar point to prepare the common standard on setting of the evaluation objective, evaluation standard, evaluation category, analysis method, drawing preparation and utilization.

During the establishment process of the plan, the linkage of the environment plan and the spatial development planning is made by direct participation or consultation in the mutual planning process. When structuring of the participant of planning establishment, it shall guarantee the participation of both sides of the plans and shall form the system and condition to confer on the plan at any time.

5.1.3 Linking of Planning Agency

The linkage of planning subject considers the characteristics for each planned special unit, and select the plan to mutually consider after separately establish the other subjects for each and the plan to establish the integrated plan for the integrated subject. Although the National Territorial Development Plan and the National Environment Conservation Plan of the national land unit shall separately be established by different agency (the Ministry of Construction and Transportation and the Ministry of Environment), the main bodies of the two plans shall share the information and opinion in close relationship.

Considering the realistic condition of administrative organization and policy operation in the provincial unit and establish separately in other department, the planning details between the two planning departments shall closely be discussed. The Urban Comprehensive Plan and the basic plan for scenic ecology are prepared separately from other departments and go through the consultation process, but on the matters not stipulated partially, the position of each party shall clearly be presented to find the compromise in the lower planning stage.

The Urban Management Plan and the landscape ecological plan are prepared separately in principle, but the landscape ecological plan is needed to reflect in priority than the Urban Management Plan. The district unit plan and the green planning are established together with the department in charge of spatial development plan and the green planning is not prepared. However, the environment plan goes through the process of inspecting the plan details following the basic information such as the biotop mapping.

5.1.4 Linking of Planning Time

The national environment conservation plan that is in the mutually supplementary relationship with the National Territorial Development Plan is expected to be

established in the similar period of 2004~ 2005. Accordingly, the first national environment conservation plan and the Forth National Territorial Development Plan may be prepared on the same period. At this time, the consultation and joint works of these two plans will be more important than anything else.

The provincial environment conservation plan and the basic plan of scenic ecology would be good to consider the spatial development plan by establishing slightly earlier (before 2005) than the establishment period of the comprehensive provincial plan and the Urban Comprehensive Plan. The environment information such as biotop mapping is not structured that the general basic information is structured while the environment plan is established at the same time.

The Urban Management Plan and the landscape ecological plan stage are very important for its planning establishment period since they may assert the effect of practical linkage. The issue is to prepare the frame to resolve the conflict of the two plans and the structuring of basic information in a system. Accordingly, there has to be regulations on environmental map including the biotop mapping as well as the regulation on tuning environmental damage by development.

5.1.5 Building up of Consultation Condition of Planning Details

In order to practically secure the linkage of the details of the spatial development planning and environmental planning system, it is very important to prepare the condition to 'confer' between the plans. The spatial development planning and the environment plan shall go through the process of revision and supplement for the planning details while making mutually supplementary functions.

In order to building up the consultation condition, the planning conference organization as the systematic tool for the conference of two plans is newly structured or may perform such a function including the existing urban planning and the review committee of the environment plan. Actually, it is important to have the attitude to replace the opinion from time to time in the planning establishment process for persons participating in actual plan without the binding onto the formation or the system itself. For this purpose, it is important to structure the basic information needed in establishing the both sides of plans. Because, when the opinion of both sides is in conflict, the objective basis on land and the atmosphere to confer would resolve it.

5.2 Linking Method of the Spatial Development Plan and Environment Plan

5.2.1 Space of Environment Plan and Biotop Mapping

The environmental map that contains the ecologic information of the space may be utilized as the basic data at the time of establishing the spatial development planning that it may take the role of core tools to link the environment plan and the spatial development planning. In order to make efficient environment conservation, the ecological map is prepared on the basis of survey on environment and ecological information in the area, and prepares the legal device to reflect it in the process of establishing the spatial development plan.

The biotop mapping (Kim 2001) is one of the environmental maps shown on the drawing by evaluating the characteristics of land and by formulation following the certain form on the basis of ecological characteristics on animal, plant, climate, geography, geology, and irrigation of land of certain district. The biotop mapping is a useful tool to make comprehensive evaluation for the ecological environmental characteristics of the space that it is very useful to the environment plan that has the ultimate objective in classifying the preservation site and the useable site.

The preparation system of the biotop mapping may be classified into the biotop mapping and the detailed biotop mapping, with the former being the provincial unit biotop mapping and the later being utilized in city and gun. Under the view to provide ecological information to promote to the nature-preserving direction for the land use planning, the biotop mapping is one that contains the details of the ecological land use planning.

5.2.2 Preparation and Utilization of Landscape Ecological Plan

The landscape ecological plan is the plan to form the organic connection system of scenes through the appropriate supplement and adjustment of land use for the protection or improvement of spatial mutual reaction and individual characteristics of natural resources having the mutually different scenic structure. The landscape ecological plan takes the role to provide the appropriateness of other land use planning to assess and decide in ecologic sense to provide the reduction plan of impact on the environment.

The landscape ecological plan is a specialized plan for nature protection and scenic management while it is Querschnittorientierteplanung (cross-section oriented planning) to reflect the details of scenic management plan with the horizontally crossing the vertical spatial development planning system (Riedel and Lange 2001). The landscape ecological plan is made up in two parts including the analysis and assessment on the status of nature and scenery and the environment management plan establish on its basis. The details that are treated in the environment management plan are the matters related to nature circulation system and restoration, matters on protection and management of biotop and organism, matters on the protection and management of scenery, and the matters on resort and green area use.

5.2.3 Regulation on Scenic and Natural Environmental Damages (hereinafter 'Scenic Damage Regulation')

Scenic Damage Regulation is the regulation to mandate for action taking for compensation or replacement in the event of having the damages while it prohibits the damages to the scene and the natural environment occurring by the national land development. From the preservation subject for environment plan, the Scenic Damage Regulation is secured for systematic basis for adjusting the expected and unavoidable damages following the spatial development planning.

When the development was to make for the place classified as the preservation for the landscape ecological plan established on the basis of environmental map including the biotop mapping, the 'Scenic Damage Regulation' takes the standard role in presenting the direction to measure along with the evaluation on damages.

Under this regulation, it has to include the matters considered for the damages to the scenery and natural environment, plans to reduce or replace on the space impacted if the natural environment is influenced, matters to cancel the project if the degree of damage on the nature and scenery is not to be supplemented.

The systematic basis on the Scenic Damage Regulation shall have the detailed contents specified on the Basic Act on Environment Policy and the spatial development planning laws that are applied to the spatial development planning and the environment plan. The detailed matter is deemed to determine in the ordinance of the local governments to define appropriately to the situation of the local governments.

6. CONCLUSION

6.1 Integration of Environment and Development

The sustainable national land management is possible when the development and the environment are considered together (VROM 1999). The act like the land use and facility installation for human activity provides direct impact on the natural environment changes that the spatial development planning has to be considered on the same location with the environment plan. This is the basis to the realization of the pro-environment national land, and it shall be the basis of practicing the sustainable development concept.

For this purpose, there is a need of change in the view toward the nature (Jin 1998, Leopold 1966, Rolston 1989, Sagoff 1991). In addition to the economic value of nature, it requests the change of thinking system recognized for the social-cultural value and the ecologic value. In the meanwhile, it would be not wise to have the national land management policy to focus exclusively on ecological point since the rampant development to this point emphasize only the economic efficiency. The balanced way of thinking in viewing development and environment together is required. Development may be deemed as a way of environment conservation. Through the development, the space for human is structured, but it is another change of the natural environment that whether the environment conservation is to go with the flawless flow of the natural ecology following the degree of assimilation of the development action with the nature.

Land and environment cannot be separated (Leopold 1966). The conduct of developing and using the land resource for the convenience of human cannot be separated from the environment conservation action. Accordingly, the national land management policy shall establish the system to consider both the development and the environment conservation simultaneously. This is the reason to link and integrate the spatial development planning and the environment plan that are the basis of policy decision. Accordingly, the linkage of spatial development planning and environment plan is an essential element of space management and for the right use of the national land.

For this purpose, what is needed is the conversion of awareness that recognizes the value of intrinsic nature itself. Current classification of productive, public benefit

and preservative values of nature (Sagoff 1991) that we use is the instrumental value of our experienced nature. The national land management that values such an instrumental value has to be the development oriented for the convenience of human. When the land resource based on the importance of nature is used, the national land management where men and nature co-exists (Choi 1995). The sustainable national land management may be achieved through the linkage of the spatial development planning and the environment plan.

6.2 Suggestions in Policy

For the sustainable spatial development plan and development, the new national land related system is applied from 2003. For the sustainable environment, the Basic Act of Environment Policy was revised and now the Natural Environment conservation Act is to be revised. The national land related system includes the matters to consider for environment in many provisions of the laws. Under the environment related system, the places with the value to preserve and the places that are not secure the basis to treat the damage to the natural environment and the disharmony of nature following the development.

The linkage of spatial development planning and environment plan is for the sustainable national land management. By changing the frame of the planning system for the national land management, it attempts to promote the sustainable spatial development plan and development. Under the study to this point, the direction and major means for the linkage of the two planning systems are sought. In conclusion, the following is a few points that this study emphasizes and the point indicated by the study for the linkage of the two planning systems.

First, in establishing the spatial development planning for linking the spatial development planning and the environment plan system, it is needed to have the practical device to consider the environment. In the new national land related system, there are many matters included to consider the impact in advance or neglecting the damage to the environment and the rampant development raised by various developments. In order for the details of this legal system to have the substantive effect, the practical means shall be considered. Linking of planning system alone doe not make the sustainable national land management. Strengthening of environment of the spatial development planning is an essential condition for the planning system.

Second, the strengthening of environment of the spatial development planning has to be made with the environment plan in mind. To this point, the spatial development planning was the upper-most plan from all national land related plans, but under the national environment conservation planning under the Basic Act of Environment Policy, the promotion of policies considering the mutual relativity is required with the national land. The reality of the environment plan is yet to be solidified that the Ministry of Environment shall closely cooperate with the Ministry of Construction and Transportation in the process of structuring the actual body of the environment plan. In addition, the Ministry of Construction and Transportation shall discuss with the Ministry of Environment in preparing the detailed instruction

on the various considerations of environment mentioned in the spatial development planning system. Such a process enhances the practicality of both plans and promotes the policies that consider the "environment" in the process of development requiring the new national land and the environment related system.

Third, there are many tasks to resolve in order to link the two planning systems, but the most urgent thing is to structure the basic information. Structuring the basic information used commonly under the spatial development planning and the environment plan is the beginning of the two planning system linkage itself. For this purpose, on the basic survey to promote jointly, it enables the implement through the relevant system and revised supplement of the instruction. For this purpose, the joint work on its expression on the survey content, method, period, utilization scope, assessment and the survey result shall be made. Through this, the environmental mapping including the biotop mapping is jointly produced.

Forth, the Ministry of Environment shall urgently prepare the instruction for environment plan before preparing the environment plan. When making the establishment instruction, the details of plan to be prepared for each environment stage shall be cleared in detail. At this time, it is important to refer to the details of each spatial development planning stage. In particular, there is a need to review the plan to look at the details to be linked in each planning (as the obligatory matter).

Fifth, the most needed one to promote the linkage of the two planning systems is the condition to confer on the "plan" by the experts and the departments related to the two plans. In the countries where the plans are made with the linkage or integration has the sufficient consultation between the planner and person in charge although they have the devices such as the system, guideline and others. Consultation is based on the understanding on the other's plans and basic information that enables them for objective decisions. For our case, we obviously need to have these points, but we may need to review the plan to form the consultation group for the linkage of the planning system.

Sixth, the linkage of the two planning system means not only the simple planning details but also the linkage of planning stage, planning period, and role of planning. Looking from the point of view of the spatial development planning, the linkage of planning does not newly begin but is a link with the environment plan during the progress that it is not that simple. Accordingly, it is a matter requiring the complete re-review and the turning around on the planning frame. For this purpose, a remarkable readjustment on the existing system is required. It means the re-review of planning establishment process, establishment and others that have been customarily done as well as the frame of organization that has been undertaken this.

To promote such a problem, there is a demand for changes including the viewpoint of national land, recognition on nature and the like. Currently our society has the growth-first paradigm like as the Dominant Social Paradigm that had been forming our value point is gradually losing its strength. In the future, our way of thinking is to be made by the ecology-oriented paradigm like as New Environmental Paradigm. This New Environmental Paradigm requires the value point to think the environment first. Such a change of recognition enables the sustainable national land management, and to respond to such a change, the frame of the planning system

shall be converted. This research is expected to provide the basis for converting into the planning system and the paradigm shift for the planning.

7. NOTES

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[i] Spatial development plan here means the spatial development plan specified under the National Territorial Development Planning Act including National Territorial Spatial development plan, Comprehensive Provincial Plan, Urban Plan, District Unit Plan and the like. In addition, the term of "Spatial development plan" in this paper also is used in the same concept as spatial development plan.

[ii] It means spatial development plan in environmental part from the national environmental preservation plan, and is a plan to treat the damages to the natural environment and pollution issues caused by the development. It includes the existing natural environment conservation planning, scenic planning and others, and in particular, it is defined with a similar characteristics with the landscape ecological plan of the Nature Protection Act of Germany.

[iii] For the two planning system, the attempt has been first made that there are many tasks to resolve for the linkage. Here, the focus is on seeking the ways and means needed to study for the larger direction and linkage.

[iv] For the regional plan, the specific zoning plan of Comprehensive Planning Act of National Land Construction, capital area clearance plan of Capital Region Clearance Planning Act, the metropolitan development project plan under the Act on Regional Balance Development and Regional Small & Medium Business Development, Jeju-do Comprehensive Spatial development plan under the Special Act on Jeju-do Development are excluded. However, the urban development project that is similar to the urban planning and development project for housing development scheduled district under the similar Housing Development Promotion Act are excluded, but it is applicable to the urban planning that the linkage plan may be applicable. In particular, when reviewing for the biotop mapping utilization plan, the housing development project may be included.

[v] In addition, for the laws related to environment, release regulation and management, laws related to "atmosphere, water and waste substance" and water laws related to the water treatment management, laws to manage drinking water are excluded.

[vi] Preservation In the newly revised (Nov. 8, 2002) Basic Act of Environmental Policy, the contents and the name are changed into national environment conservation planning.

[vii] In the event of Berlin, Germany, the environmental map is prepared on 8 items including, soil, water, atmosphere, biotop, land use, traffic and noise, and from this, the biotop mapping is used in considering in advance for the subject to protect from the environment damages following the development, including the landscape ecology status.

[viii] This is in a form of policy report that arranged the environment policies that it is difficult to say this as the environment plan that is asserted under this study.

[ix] The Ministry of Environment inquired the "Basic Study for Establishing the National environment conservation plan" (October 2001 - April 2002) and "Study to Establish National environment conservation plan" (June 2002 - July 2003) to the Korea environment Institute.

[x] For example, the status chart is prepared on the basis of biotop status and arbor status, and prepare on the details of legally protected biotop boundary, protection of major biotop and setting of boundary for management, means for nature protection and scenic management, and the presentation for the plant plan of major arbor.

8. REFERENCES

Bennett, G. 1991. "The history of the Dutch National Environmental Policy Plan." *Environment* 33: 6-9, 31-33.

Berry. J. and Mcgreal, S. 1995. *European Cities, Planning Systems and Property Markets*. E. and F. N. Spon, London.

Bouwer, K. 1994. The Integration of Regional Environmental Planning and Physical Planning in the Netherlands. *Journal of Environmental Planning & Management* 371: 107-116.

Centre for Environment and Planning. 2000. *A Comparison of Environmental Planning Systems Legislation in Selected Countries*. Bristol: University of the West of England.

Choi, Y.-K. 1995. *The Nature of Forest Values toward Ecosystem Management*. Doctor Philosophy Theses, Department of Land Use and Landscape Planning, Agricultural University of Norway.

Choi, Y.-K. 2001. *The Integrity of Planning System between Spatial development planning and Environment Planning*. KRIHS, Korea

Dienst Ruimtelijke Ordening-Amsterdam. 1998. *Milieuzones in Amsterdam*. Dienst Ruimtelijke Ordening, Amsterdam.

European Commission. 1999. *The EU Compendium of Spatial development planning Systems and Policies: The Netherlands*. Luxembourg: Office of the Official Publications of the European Communities..

European Commission. 2000. *The EU Compendium of Spatial development planning Systems and Policies: France.* Office of the Official Publications of the European Communities, Luxembourg.

European Commission. 2000. *The EU Compendium of Spatial development planning Systems and Policies: United Kingdom*. Office of the Official Publications of the European Communities, Luxembourg.

Expert Group on the Urban Environment of the European Commission. 1996. *European Sustainable Cities report*. Office for Official Publications of the European Communities, Luxembourg.

Farmer, A. Skinner, I. Wilkinson D. and Bishop, K. 1999*. Environmental Planning in the United Kingdom.* A Background Paper for the Royal Commission on Environmental Pollution. U.K.

Freistaat Thüringen. 1993. *Landesentwicklungsprogramm Thüringen*.

Freistaat Thüringen. 1999. *Regionaler Raumordnungsplan Nordthüringen*.

Hajer, M.A. and Zonneveld, W. 2000. Spatial development planning in the Network Society - Rethinking the Principles of Planning in the Netherlands. *European Planning Studies* 83: 337-355.

Jin, K.-H. 1998. *Environmental Ethics*. MinEum-Sa.

Kim, H.-S. 2001. *The Technique for Development of Eco-City*. MOCT (Korean)

Korea Research Institute for Human Settlements (KRIHS). 2001. *The Report of Seminar; Spatial development plan System for Sustainable Development.*

Lemons, J. 1995. Sustainable Development and Environmental Protection: A Perspective on Current Trends and Future Options for Universities. *Environmental Management* 19: 157-165.

Leopold, A. 1966. *A Sand County Almanac*. Ballantine, New York.

Miller, D. and de Roo, G. 1996. Integrated Environmental Zoning: An Innovative Dutch Approach to Measuring and Managing Environmental Spillovers in Urban Regions*. Journal of the American Planning Association* 62: 372-379.

Miller, D. and de Roo, G. 1997. Transitions in Dutch Environmental Planning: New Solutions for Integrating Spatial and Environmental Policies*. Environment and Planning B: Planning and Design* 24: 427-436.

Miller, D. and de Roo, G. 1997*. Urban Environmental Planning: Policies, Instruments and Methods in an International Perspective*. Ashgate, Aldershot.

Miller, D. and de Roo, G. 1999. *Integrating City Planning and Environmental Improvement: Practicable Strategies for Sustainable Urban Development*. Ashgate, Aldershot.

Ministerium für Umwelt, Natur und Forsten des Landes Schleswig-Holstein. 1999. *Landschafts-programm Schleswig-Holstein*. Berlin: Ministerium für Umwelt

Ministry of Environment. 2000. *Environmental-Friendly Urban Planning*

Ministry of Environment. 2001a. *The National Environment Plan*

Ministry of Environment. 2001b. *Environmental-Friendly National Land Management*

Ministry of Environment. 2002. *The Basic Study for the Comprehensive Environment Plan*

Ministry of Environment. 2000. *The Comprehensive Environment Plan* (Japanese)

Ministry of Construction. 1994. *The outline of the Green Plan* (Japanese)

Ministry of Housing, Spatial development planning and the Environment (VROM). 1999. *Area-specific Policy works: Environment and Spatial Development Planning in Partnership*. The Hague: VROM.

Ministry of Housing, Spatial development planning and the Environment (VROM). 2001a. *Making Space, Sharing Space, Summary Fifth National Policy Document on Spatial development planning 2000/2020*. The Hague: VROM

Ministry of Housing, Spatial development planning and the Environment (VROM). 2001b. *Where There is a will There is a World: Working on Sustainability, Summary 4th National Environmental Policy Plan*. The Hague: VROM

Riedel, W. and Lange, H. 2001. *Landschaftsplanung*. Specktrum, Akad. Verl., Heidelberg, Berlin.

Rolston, H. 1989. *Philosophy Gone Wild* (pp. 91-117). Prometheus Books, Buffalo. New York.

Sagoff, M. 1991. "Zuckermann's Dilemma: A Plea for Environmental Ethics. *Hasting Center Report* 21: 32-40.

Senatsverwaltung für Stadtentwicklung und Umwelt-schutz. 1994. *Landschaftsprogramm Artenschutzprogramm Berlin*. Senatsverwaltung für Stadtentwicklung und Umwelt-schutz. Berlin.

Senatsverwaltung für Stadtentwicklung, Umwelt-schutz und Technologie. (1999). *Umweltverträlichkeitsprüung und Eingriffsregelung in der Stadt- und Landschaftsplanung*.

Stadt Eckernföde. 1991. *Landschaftsplan der Stadt Eckernföde*. Eckernföde: Stadt Eckernföde.

Steiner, F., Gerald Y., and Zube, E. 1988. Ecological Planning: Retrospect and Prospect. *Landscape Journal* 7: 31-39.

Sung, H.-C. 1996. *The Establishment of Green Network*. Kyonggi Development Institute.

Umweltbundesamt Berlin. 1995. *Umweltschutz in der Flühennutzungsplanung, Bauverlag GmbH*. Umweltbundesamt Berlin.

Umweltbundesamt Berlin. 1997. *Umweltschutz in der Bebauungsplanung, Bauverlag GmbH*. Umweltbundesamt Berlin.

van der Straaten, Jan. 1992. The Dutch National Environmental Policy Plan: To Choose or to Lose. *Environmental Politics* 1: 45-71.

http://www.bmu.de/download/dateien/bng_entw1.pdf

http://www.me.go.kr

http://kosis.nso.go.kr

http://www.thueringen.de/rolp/Instrumente/Plaene/Thueringen/LEP/Lep1993/Text/Landesentwicklungsprogramm-Thueringen-1993.pdf

http://www.thueringen.de/rolp/Instrumente/Plaene/Regionen/RROP/Nord/Text/RROP_Nordthueringen.pdf

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& TOMOKO KOGA

CHAPTER 18

LANDSCAPE ECOLOGICAL APPROACH FOR RESTORATION SITE OF NATURAL FORESTS IN THE OTA RIVER BASIN, JAPAN

1. WATERSHED AS A LARGE LANDSCAPE UNIT

The concept of landscape ecology (Forman and Gordon 1986) is the integrated understanding of nature by considering the structure, function and changes of ecosystem. Landscape mutually reacts to human activities and natural environment, so this idea must be undertaken in real world. Therefore, the accountability of landscape ecology has been realized and disseminated.

Quite a few studies have been conducted from different directions and angles in Japan. Some of the latest researches are Kamada and Somiya (1995), showing a comparison with time and space of landscape structure due to the land use structure and its changes, Kamada and Nakagoshi (1996) demonstrating a spatial comparison of regional characteristics, and Sakamoto *et al.* (1995), indicating the procedure of forest area management planning from a point of land management view.

Most of the researches have implemented one-dimensionally comparison among years or among regions of landscape structure. The entire topographic approach towards the river basin having several branch reaches has not been taken into consideration. Research proposal of the whole environmental conservation appropriate to the regional condition, has been implemented (Nakagoshi 2000)

It indicates an expression stating that a unit where fauna and flora are existing in a certain expanded area, as well as a unit where life forms exist scattered but mutually and closely related to each other, or on the basis of water circulation, the minimum ecological unit is required to understand the integrated ecological functions.

Another point of view is that it is considered as a corridor relating largely to the mutual reaction of flora and fauna. It has dealt with the watershed where it is largely mutually reacted among animals, researching that environment of location in the watershed forests, or Kamada *et al*. (1997) studied that precisely concerning the watershed area while understanding both micro scale of plant community and macro scale of land use changes. Furthermore, Lee *et al*. (1989) established the basic

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information data base of environment while understanding the global environmental structure, which is now part of this study. Nevertheless, it is now inevitable to not cover the whole watershed area for understanding the influence of several aspects such as forest logging, land development of mountain area, which certainly cause affects to the lower reaches as far as the seacoast. It has become a critical issue in the river basin where rivers flow into the Seto Inland Sea such as the Ota River.

Therefore, rivers and other surrounding components must be grasped as one unity which is composing of the rich natural environment. Hydrologic and topographic conditions of the watershed area as well as the biological community keep changing as one system. This system requires the biodiversity conservation planning to be undertaken as the environmental conservation of the whole watershed area. It summarizes the advantages of landscape ecology of watershed area base as (1) it is the landscape facilitated to understand the natural geographic map (ridges, water lines and roofs function as a nature route). (2) taking the water circulation as the basis, the ecological unit is easily understood integrated ecological function (3) it includes the same-type landscape mosaic, at the same time. Naturally, it composes the different-type of landscape in a higher level connecting to the nearby reaches, and (4) it is an administrative area for the national land management through river management programs in Japan.

2. ADVANTAGE OF ECOTOPE BASED APPROACH IN A WATERSHED SCALE

The factors composing of ecotope, have long been studied individually, being separated from each one of the factors. The Environmental Impact Assessment Law in Japan enacted in 1999, has however, raised an anonymous concern, that plans of future development and land use must be drawn taking all the factors into consideration, covering the entire natural environment, where nature exists as one spatial unity. This policy is certainly succeeded in the Law for Promotion of Nature Restoration enacted newly in 2003.

The Ota River basement area/basin in western Hiroshima Prefecture, the total area of 1,700km^2 is targeted in this study. The whole area is recognized as one unity of natural section, then a topographic map, a surface layer geologic map and a vegetation map, were triply over-laid to complete an ecotope map. At this stage, the regional characteristics of this study area was understood by showing the distribution selectiveness of biotope in relation to geotope. Ordination was carried out by using the selective index (Jacobs 1974).

Watershed has been demonstrated in some research; *e.g.* mutual reaction of forests and rivers in the watershed area on a micro scale (Nakamura 1995) and watershed management (Lee *et al.* 1989). Quite few cases have related the macro scale level like the Ota River basin to land use. Taking the entire watershed area into consideration as one unit, regional characteristics deriving from the targeted area as components of landscape elements shall be understood. Then through regional land evaluation, diversified characteristics of the watershed in the region should draw attention in developing an integrated plan for land use, development and conservation.

Geotopes of large selective index in vegetation distribution keeps a high potentiality of having more vegetation. This is obvious from any points of view. There is a fact that it is uncertain to clarify such factors exclusively analyzing the surface covering area especially in the level of the plant community/association. The selective index is, therefore, considered as one useful method to analyze the relations between vegetation distribution and geotope in large area such as river basin. For easy understanding, the research procedure of this study is demonstrated in Figure 1.

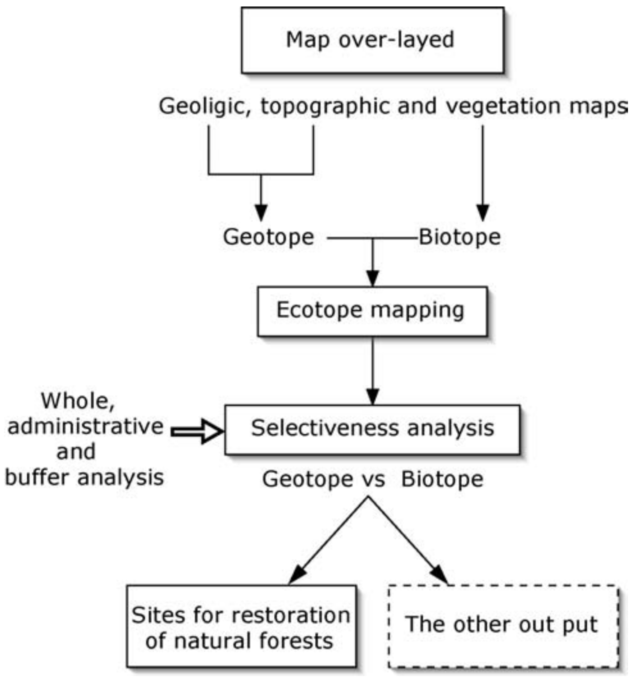

Figure1. Procedure of this research for ending of restoration of natural forest ecosystems through landscape ecological method

3. ECOTOPE MAPPING AND ECOTOPE CHARACTERISTICS

The basic database is from the topographic classification map of 1:50,000, 2 types of surface geologic map layer, 16 pieces of map which are attached to the land classification basic research in Hiroshima Prefecture. Unified topographic units were 13 forms and those of rock were 13 kinds. These data were input into the geographic information system: GIS (Arc/info, ESRI), and it was constructed. Also, the data base of the current vegetation map which was made from the 3rd and the 4th Natural Environment Conservation Basic Research (Vegetation Research) being included in the Natural Environment GIS Data published by the Environmental Agency. Legend of the vegetation map consisted by 29 plant communities and 6 landuse types, total

35. The scale of this newly developed data base is also 1:50,000. The ideal map scale is 1:25,000 in landscape ecology (Leser 1991), however in this research, a wider area was targeted, also the existing data were used, so no different scales was recommended, and 1:50,000 scale was appropriately considered appropriate.

These 3 maps were over-layed on GIS, and 809 types of ecotope and 35,507 elements were identified.

Some ecotope types had to be selected for the further research, since the unnecessary trifle ecotopes which are called strip polygon that can be seen in the marginal difference of each landscape component, are all included in the data. The strip polygon makes the data analysis hard, causing impossible combination of landscape element. Therefore, in this study, we selected the ecotope types according to the watershed area, the problems were solved as following. At first, the areas covering over than 1 % of the whole watershed were used to explain approximately 70% of the total area. However, it was not sufficient to understand and clarify the specific characteristics of the Ota River basin with various landscape factors. The minimum requirement of the area ratio, which can clearly explain the landscape structure of the watershed while increasing the number of targeted ecotope types, was over 0.01%. Therefore, these were used in analysis (Fig.2). The ecotope elements covering over 0.01% area of the total watershed area, can be used to explain the entire system of the river basin, and it includes the landscape factors as well.

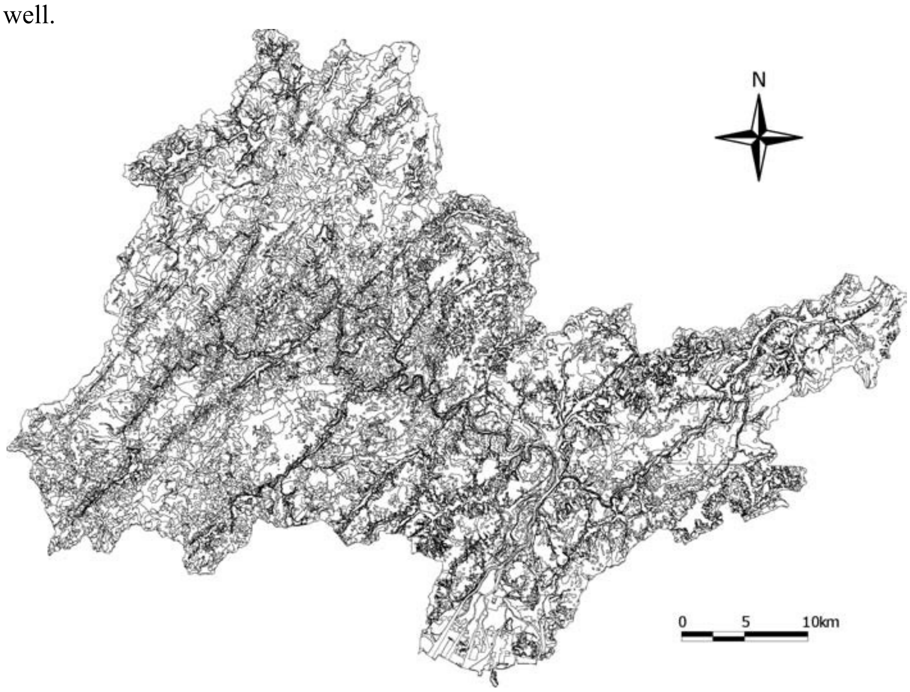

Figure 2. Ecotope map in the Ota River basin excluding small area ecotopes less than 0.01% (1.7ha) to total area (1,700km^2)

The selective index Dij of Jacobs (1974) were used to analyze the variation of biotope against geotope type. The index of selectiveness of Jacobs was originally delivered from the selectiveness of fish feeders, and this was used for plant community distribution in order to find out variation of geotopes of individual biotope type showing this formula (1);

Dij=(rij-pj)/(rij+pj)-2rijpj (1)

Here, Dij signifies the selectiveness of vegetation i distribution in geotope type j, and rij is the ratio of geotope j in vegetation i, pj is the ratio of geotope j in the whole. Dij is the result of the deduction of +1 from -1, then the area ratio is kept wider compared to geotope j while nearing to +1. To the contrary, the area ratio becomes small compared to geotope j while nearing to -1. Zero indicates that the area ratio of geotope j in not much differ comparing to vegetation i. One of the results is demonstrated in Figure 3.

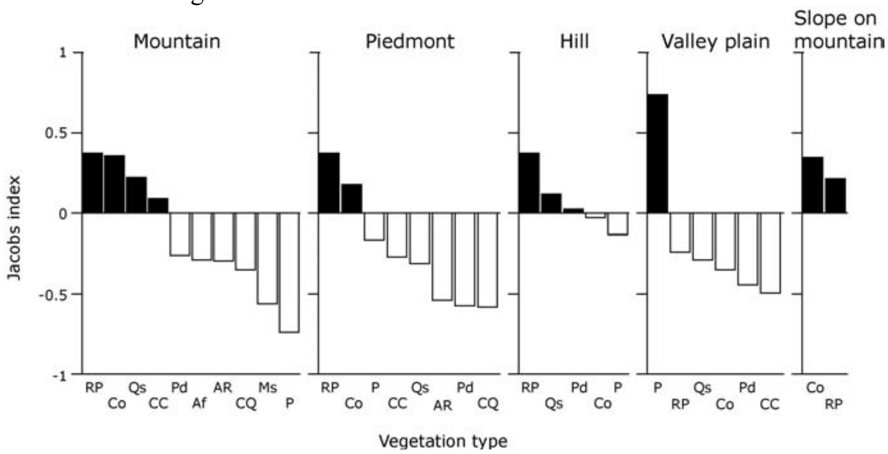

Figure 3. Geotope selection by vegetation/biotope type on granite in the Ota River basin Abbreviation of plant communities and land use types. RP: Rhododendro reticulati-Pinetum densiflorae, Pd: Pinus densiflora community, CQ: Castaneo-Quercetum crispnlae, Qs: Quercus serrata community, CC: Cryptomeria japonica*,* Chamaecyparis obtuse *plantation, AR: Aralio-Rubetum crataegifolii, Ms: Miscanthion sinensis, P: Paddy field, Af: Abandoned dry field, Co: Cut over site*

Here the meaning of the indices of +1~+0.5, +0.5~0, 0~-0.5, -0.5~-1 is understandable, so facilitated it was divided into 4 categories, and the relations of geotopes to respective vegetation types were studied. This method has been useful for analyzing the ecotope distribution in a small river system of the Ota River (Hikasa and Nakagoshi 2000). We adopted this method to larger area here.

In the use of indices, the targeted ecotope type covers 0.01% of the total watershed area, and includes the plant community/association of natural vegetation, substitutional vegetation, and plantation.

4. SUPPLEMENTARY ANALYSIS BY GEOGRAPHIC INFORMATION SYSTEM

Adding the socio-economic factors, 2 landscape characteristics; administrational ones within the basement area and artificial influence according to the distance from the city center, were respectively identified. The completed ecotope map was overlaid with the administrational division for the former result, and the latter was overlaid with a buffer of every 5km from the city center (the city hall of Hiroshima). Through comparison of those characteristics, almost same results were taken to draw a land use plan in consideration with the landscape construction.

The administrational one was divided into different categories according to the vegetation type either natural or substitutional. The distributional pattern to each type of geotope due to the calculated selective index in every administration area, resulted in demonstrating characteristics of each group. The number of ecotope types counts the most in 30-35km in the distant-from-the-city-center one, as a result, the number of the ecotopes with the large distributional pattern reaches its peak in the same 30-35km This result clarifies that the analysis from various viewpoints (directions) using indices demonstrate a unique relation between natural vegetation and the types of geotope, as well as among the vegetation groups.

The Environmental White Paper of Japan states that nature condition has often been researched superficially, paying attention merely to individual component, which is causing that the whole view has been ignored. The large-scale viewpoint must be undertaken when drawing a development plan including land use which caused a strong impact to ecology. The selective index method is no longer influenced by area covering ratio of the targeted area and realize to understand the entire landscape structure, therefore, it is particular significant to construct appropriate plans to nature.

5. OVERALL ECOTOPE PERFORMANCE

As a result of overlaying 3 different maps, 809 kinds of ecotope and 35,507 individual ecotope elements were obtained. The object for analysis was those whose area covers over than 0.01% of the total watershed area, and those which are classified in the map of the Environmental Agency as natural vegetation or substitutional vegetation. Among them (1) variation of vegetation distribution in the whole Ota River basin (2) differences in vegetation distribution according to the administrative units (3) changes of vegetation distribution in the distance from the city center, are showing in Figure 4.

When the ecology is considerable used for land use planning, what would be important to realize effective land use? In fact, the area of indispensable vegetation tends to be smaller, and attention is often paid to a larger patch and substitutional

vegetation covering the most area of watershed, consequently, the expected ecotope with important vegetation would be excluded. Therefore, this study tries to protect exclusive area where important vegetation grows. Sakamoto *et al*. (1995) mentioned, however, that when certain endangered species are going to be protected, studying only the growing area of those species is not sufficient, but a wider area covering the surroundings of the habits must be included particularly, to conserve the growing environment. This signifies that when a new development plan is drawn which might cause some changes to the ecological system of a region, the whole area affected by the development should be considered, then substitutional measures must be planned. To deal only with the area of the growth of the important vegetation type is insufficient, but the surroundings as well as other areas with similar natural features where there is a possibility of such an important vegetation growth must be considered

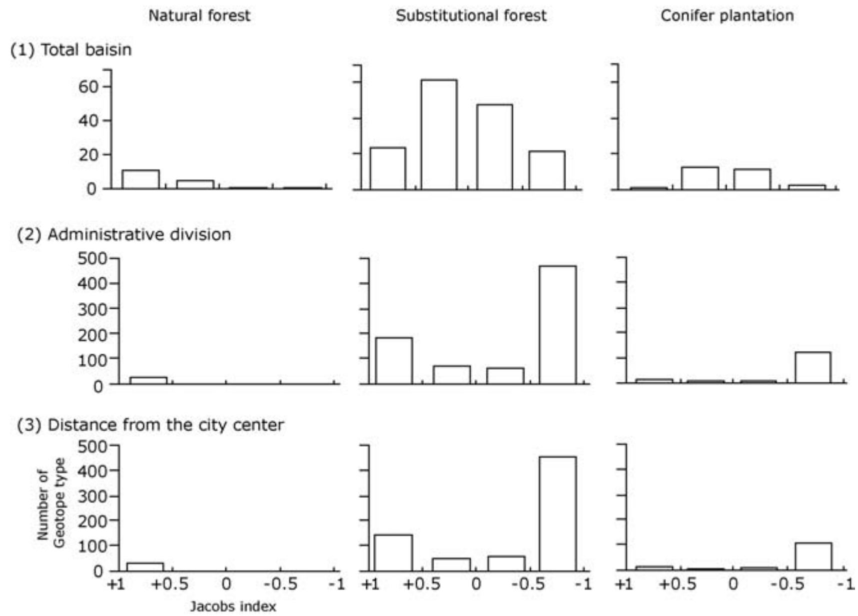

Figure 4. Selectiveness of three giotopes of biotope in different GIS analysis (1) total basin, (2) administrative division, and (3) distance from the city center of Hiroshima. Natural forests contain 7 forest communities. Substitutional vegetation consists by secondary pine and oak forests, cut over area, secondary grassland where the possible ecological succession occurred. Conifer plantation is Cyptomeria japonica *or* Chamaecyparis obtuse *woods.*

The Environmental White Paper states that the natural mechanism has been dealt individually with structural components, and rarely understood as one unity. It is essential to understand the landscape structure of the whole region which are divided by natural circulation like in watershed. Kamada and Somiya (1995) having a study of regional comparison of time and space, states that specific measures should be

considered while taking the information on a landscape level. This signifies that it is no longer effective to deal with a research on a regional base, and a wider area and its surroundings must be involved. This statement mentions about an effective research method against this study.

6. POSSIBLE RESTORATION SITES FOR NATURAL FORESTS IN THE BASIN

It is obvious that natural forests require the narrow habitat (Fig. 4). This was clearly observed in any conditions after the calculation of selective index for every natural forest. In this study, we can suggest the appropriate geotopes where the restoration project of natural forest should be done showing Figure 5. This map is actually a final product of the research concerning the natural forest issue. Detail explanation of each geotope for potentially good site for restoration is not discussing here, because it needs so long explanation and fine figures.

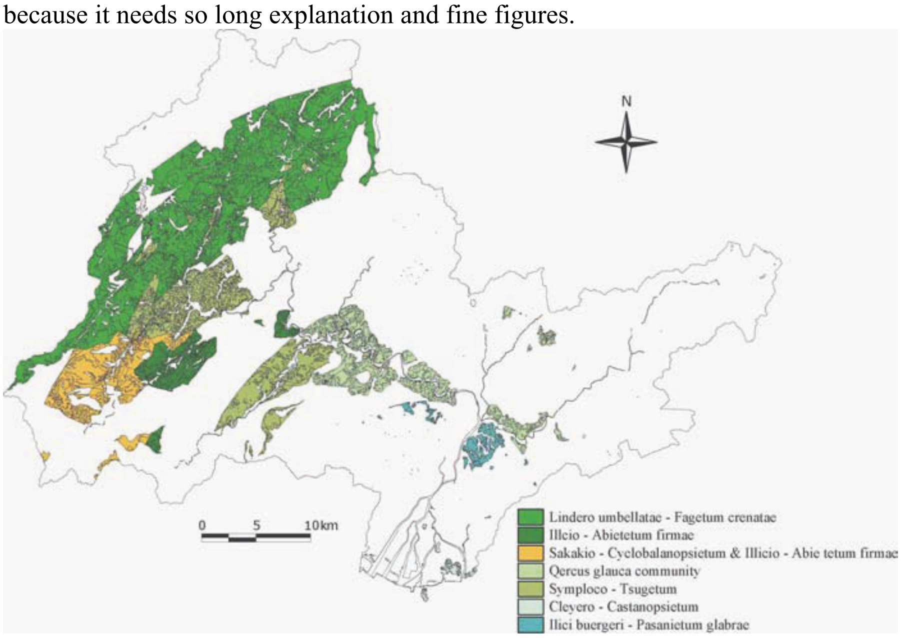

Figure 5. Potential distribution of actual geotopes appropriate for carrying the restoration project of natural forest ecosystems (See Color Plates, p. xx)

The important argument which we reached is the potential natural vegetation, in this case potential natural forest, have not been the same potential for restoration so far. Those are clear site selection by natural forests. Therefore, if the restoration project is carried out in this watershed, Figure 3 is a good guide for the project. It can be concluded that landscape ecological approach is able to advice or support the decision makers to act the wise project.

Lessons from this research are so many. Perspectives are something like as follows. It is hard to conduct research only looking at the whole watershed area when the landscape structure is considered from possible socio-economic influence in the case of substitutional vegetation. Landscape ecology dealing with one spatial unit including human activities, differ from land ecology, therefore, political, social and economic backgrounds of human activities in the watershed area must be studied, and administrative units should be related to human activities as well as understanding the regional characteristic.

Therefore, in these administrative districts, cooperative system must be established in the socio-economic background. Finding the geotope type with high natural degree, and discontinuously distributing, the vegetation will be conserved. Or, by studying the natural condition such as location and environment with high possibility of the growth for the vegetation, the whole watershed area will be characterized.

Conservation of this type of area, is effective to conserve vegetation with high naturalness, at the same time, due to the housing development in recent years, places without human impact in the past has a potential human influence at this moment. This phenomenon definitely requires the future land use planning.

The outcome of this showed the areas like plantation, cultivation land, artificial grassland where human activities are highly involved in the geotope type of +1~+0.5 of selective index of natural vegetation was clearly distinguished, and it explains that even human activities indirectly influence in a natural vegetation, not only in the substitutional vegetation. In the substitutional vegetation, in addition, location in watershed clarified some variation towards geotope type. Furthermore, meteorological factors are more considerable in local situation such as north-south slopes which are sometime very important of vegetation distribution factors. In this research activity, the local environment of vegetation distribution becomes clear, thus, it enables us to draw conservation planning as well as identifying the vegetation distribution factors in details.

7. ACKNOWLEDGEMENT

We would like to express our deepest gratitude to the Environment Agency of Japan for letting me allow to use the natural environmental information GIS database. We also would like to convey our heartfelt thanks to Prof. Kimoto Sada at Kure University for giving us good advice about the aggregation of geographical features and geology legends. Finally, we thank the discussion by the ecological members in 21st Century of Excellence Program for Social Capacity Development for Environmental Management and International Cooperation to criticize the proposal in this paper.

8. REFERENCES

Forman, R.T.T. and Godron, M. 1986. *Landscape Ecology*. John Wiley, New York. pp.601.

Hikasa, M. and Nakagoshi, N. 2000. Method of analyzing spatial structure of riparian vegetation in dam construction for environment impact assessment. *Environmental Information Science* 14: 237-242. (in Japanese)

Jacobs, J. 1974. Quantitative measurement of food selection. *Oecologia* 14: 413-417.

Kamada, M. Okabe, T. and Kotera, I. 1997. Influencing factor on distributional change in trees and land-use types in the Yoshino River, Shikoku, Japan. *Environmental Systems Research* 25: 231-237.

Kamada, M. and Nakagoshi, N. 1996. Landscape structure and the disturbance regime at the three rural regions in Hiroshima Prefecture, Japan. *Landscape Ecology* 11:15-25.

Kamada, M. and Somiya, K. 1995 Spatial and temporal comparison of landscape structures in the eastern Shikoku Mountains, Shikoku, Japan. *Wildlife Conservation Japan* 1: 77-90.

Lee, D.Q. Tsunekawa, A. and Takeuchi, K. 1989. Environmental data base for Structure Modeling in the Middle Basin of Tamagawa River, Central Japan. *Journal of the Japanese Institute of Landscape Architecture* 51: 288-293.

Leser, H. 1991. Landschaftsölogie: Ansatz, Modelle, Methodik, Anwendung. Verlag Eugen Ulmer, Stuttgart. pp.647.

Nakagoshi, N. 2000. Landscape ecology; its process of development as spatial ecology. *Japanese Journal of Ecology* 5: 21-267.

Nakamura, F. 1995. Structure and function of riparian zone and implication for Japanese river management. *Transactions Japanese Geomorphological Union* 16: 237-256.

Sakamoto, T., Tsuchiya, T., Sano, M., Nakamura, F., Kaji, K., and Ito, A. 1995. A study on planning of forest watershed management based on a landscape concept. *Journal of the Japanese Forestry Society* 77: 55-65.

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RUSONG WANG

CHAPTER 19

TOWARDS ECO-INTEGRATION – ECOPOLIS PLANNING IN CHINA

1. INTRODUCTION

China is experiencing rapid urbanization and industrial transition. The pace, depth, and magnitude of these changes, while bringing about benefits to local people, have exerted severe ecological stresses on both local human living conditions and regional life support ecosystem. Urban sustainability can only be assured with a human ecological understanding of the complex interactions among environmental, economic, political, and social/cultural factors and with careful planning and management grounded in ecological principles. Unlike biological communities, human society is a kind of artificial ecosystem dominated by human behavior, sustained by natural life support system, and vitalized by ecological process. It was named by Shijun Ma a Social-Economic-Natural Complex Ecosystem (Ma and Wang 1984). Its structure is expressed as an eco-complex between human being and its working and living settlement (including geographical, biological and artificial environs), its regional environment (including sources for material and energy, sinks for products and wastes, pools for buffering and maintaining) and its social networks (including culture, institution and technology) and economic networks (the primary, secondary and tertiary industries and infrastructural services). Its natural subsystem consists of the Chinese traditional five elements: metal (minerals), wood (living organism), water (source and sink), fire (energy), soil (nutrients and land). Its function includes production, consumption, supply, assimilation, recycling and buffering, which play a key role in sustaining the city's complicated human ecological relationships (Fig.1).

In recent years, a campaign of Ecopolis development were spontaneously initiated in some Chinese cities and towns. Ecopolis is a kind of administrative unit having economically productive and ecologically efficient industry, systematically responsible and socially harmonious culture, and physically beautiful and functionally vivid landscape. It is aimed at improving its structural coupling, metabolism process and functional sustainability through cultivating an ecologically vivid landscape (ecoscape), totally functioning production (eco-industry) and systematically responsible culture (eco-culture, Fig.2).

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The essential idea of Ecopolis development is to plan, design, manage and construct the ecosystem's function of production, living and sustaining according to ecological cybernetics.

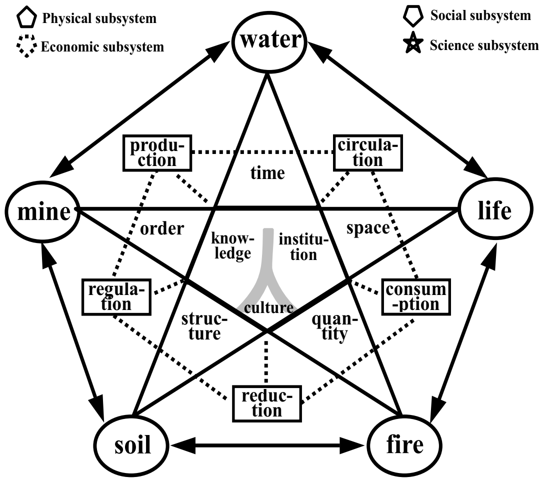

Figure 1. Social-Economic-Natural Complex Ecosystem

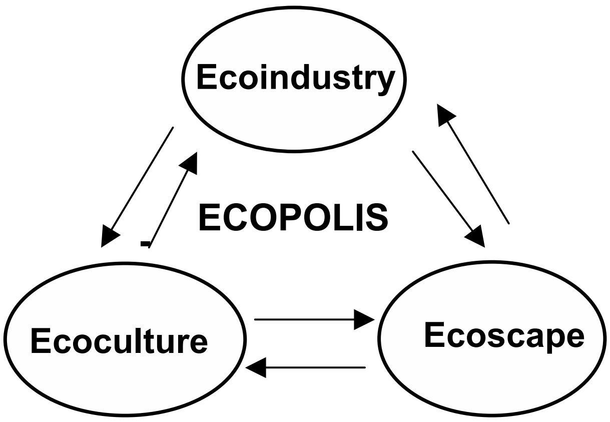

Figure 2. Three goals of ecopolis.

It is a healthy process towards sustainable development within the carrying capacity of local ecosystem through changing production mode, consumption behaviour and decision instrument based on ecological economics and system engineering. The key for its planning is ecological integration to make trade off between economic wealth

and environmental health, between material and spiritual civilization, between natural and human eco-cybernetics. Integration, demonstration, citizen's participation and scientists and technician's catalyzing are the key in its development.

2. ECO-SUSTAINABILITY

Based on the ancient Chinese human ecological principles such as the Yin and Yang (negative and positive forces play upon each other and formulate all ecological relationships), Wuxing (five fundamental elements and movements within any ecosystem promoted and restrained with each other), Zhong Yong (things should not go to their extremes but keep equal distance from them or take a moderate way) and Feng-Shui theory (Wind-Water theory expressing the geographical and ecological relationship between human settlements and their natural environment), an eco-sustainability planning was carried out forEcopolis development. The main goal is to promote eco-sustainability at four levels of natural ecology, economic ecology, human ecology and systems ecology from 5 kinds of contexts: time, space, quantity, configuration and order (Wang and Qi 1991).

General speaking, the decision making process in many rapid transition cities is based on short-term, small scale, cause-effect reasoning. People used to see physical "being" rather than ecological "becoming", and pay much attention to engineering construction, economic growth and social service by neglecting its eco-service function and man's role in it.

Planning in Chinese means a kind of integrative learning process for planners, policy makers and the publics to reach a vision of how the ecoscape is coupling, functioning and vitalizing in time, space, quantity and order; a kind of integrative design process for physical, ecological and aesthetical innovation; and a kind of interactive adaptation process for looking environmentally sound, economically productive and behaviorally feasible way of implementation. Here the key is integration of "*hardware*" (technological innovation and integrative design), "*software*" (institutional reform and system planning) and "*mindware*" (behavioural inducement and capacity building) (Wang and Yan 1998).

The ultimate goals of the systematically responsible planning are comprehensive wealth, health and faith. Wealth measures the structural state of the monetary assets, natural assets (mineral, water, forestry, soil, air and biodiversity), human resource (man powers and intellects) and social resource (institution, arts etc.); Health measures the functional state: human health, ecosystem health, and risks and opportunities on human being and their life support system; Faith measures the behavioural mode: values, material attitudes (life style, consumption customs, recycling tradition, and eco-ethics) and spiritual relations (perceptions, concepts and believes towards the totality or supernatural forces) (Wang and Ouyang 1996). The temporal, spatial, quantitative, structural and functional context are the main contents for the systematically responsible planning.

3. URBAN ECOSCAPE PLANNING

The ecoscape is the ecological landscape of the social-economic-natural complex ecosystem coupled with the contexts of time, space, quantity, configuration and order. There are four layers of ecoscape identity for a good human settlement and its environment:

- *Physical identity:* a geographical, physical, hydrological and geo-chemical pattern and process.
- *Biological identity:* a productive, diversified and vigour living system with strong ability of competition, adaptation and self-organisation.
- *Ethical identity:* an interactive reality connecting with past and future, with surrounding and other regions, symbiosis with other species and communities.
- *Cultural identity:* it is not only a shelter or producer for survival, but also an aesthetic reality, a super-organism between man and nature, a harmony between material and spiritual life for enjoyment, dedication and realization.

A sustainable ecoscape should be driven by balanced positive and negative forces to promote and sustain its development according to eco-scape theory. To turn the feedback from positive into negative, one has to comprehensively understand its dynamics and cybernetics, and to make ecologically compatible planning, design and management through technological innovation, institutional reform and behavioral inducement.

A sustainable ecoscape should be planned according to the Feng-Shui (wind and water) principles formulated in ancient China (Wang, Zhao and Ouyang 1991):

- *Totality:* geographical continuity, hydrological circulation, ecological integrity and cultural consistence;
- *Harmony* between structure and function, internal and external environment, implicit and explicit layout, nature and man, objective being and subjective value, material and spiritual goals;
- *Mobility:* constant wind and water flowing, vertical and horizontal flow, meandering streams, undulating and far stretching, and five basic movements;
- *Vitality*: luxuriant, flourishing and productive fauna, flora and soil and aquatic biome;
- *Purity:* clean and limpid water, clean and transparent atmosphere, quiet and secluded surrounding, never overloading its carrying capacity;
- *Safety*: backed by hill, enclosure, explicit, spacious, openness, easy to disperse and defense, disaster resistance;
- *Diversity* and heterogeneity of landscape, ecosystem, species, society and culture;
- *Sustainability*: negative and positive interlocking feedback, self-reliance, self-maintenance, sufficiency and efficiency, appropriate exploitation and development.

4. ECO-INDUSTRY PLANNING

There are several kinds of technology which involve the relationship between man and his environment: environmental technology, cleaner technology, nature conservation technology and eco-technology. Environmental technology aims at reduction and treatment of pollutants released by human activities; cleaner technology aims at establishing a cleaner production process within any factory so that less pollutants are produced; while eco-technology is to systematically arrange the whole human steered process from resource exploitation, production, consumption to recycling in an ecological way in order to sustain an optimum function of the total ecosystem. Eco-industry, emerged in 1990s is a combination of eco-technology to encourage ecologically sound, economically productive, behaviorally acceptable and systematically responsible technology characterized through integration of various single technology, of high technology and traditional low technology, of primary, secondary and tertiary industries, of hardware (technical innovation), software (institutional reform) and mindware (capacity building); *ecologically efficient technology* through encouraging deeper processing and comprehensive using of local resources, zero emission of hazard wastes in ecosystem scale, having long term and large scale positive environmental impacts; *profitable technology* having higher economic efficiency, lower input/output ratio, higher market potentials and higher diversity and flexibility of products renewal. TFT can be measured by the efficiency of material, energy and manpower utilization, the sensitivity of information dissemination, the products diversity and flexibility, the long term and large scale ecological impacts, and the service function to market and ecosystem (Wang, Yang and Lu 1991).

The main principles of eco-industry incubation and design are:

- Food web coupling (horizontal): connecting the different production processes and to gain positive benefit from the negative environmental impacts through sharing unused resources.
- Life cycle coupling (vertical): connecting primary production, manufacture, distribution, consumption and regeneration into one eco-industrial complex to let the production more systematically responsible.
- Ecosystem coupling (regional): combining neighbor environment, local community, dominant enterprises and other diversified sectors into one industrial ecosystem in order to internalize environmental costs and pollution could be assimilated and minimized within the system itself.
- Flexible and adaptive structure: multiple production function, diversified products and easy-to-change process rather than rigid, unified and imitation one to adapt to the changing environment.
- Functional output orientation: switching the production focus from products to social service with three kinds of final outputs: hardware (products), software (services) and mindware (value change and behavior inducement).
- Software and mindware prior to hardware: Most of the employees and their efforts should be arranged on the enterprise's planning and design, research and development, service and management, exploitation and dissemination,

training and cultivation, rather than concentration on the existed production process.

- Evolutionary management: A strong network of information feedback, technology innovation and advisory experts, and a capable, energetic and well cooperative leadership and organization; Evolutionary and self-sustaining strategies in decision making and management to cultivate vitality and to avoid or reduce risks.
- Employment enhancement: increasing rather than decreasing working opportunity especially through creating labor-intensive service sector within the industrial ecosystem.
- Respecting human dignity: working is a learning and innovation process, a social interactive and self-enjoyment engagement, rather than slaved by machine and oriented mainly to earn one's salt.
- Knowledge-based economy: eco-cybernetics based decision making, sensitive information feedback, effective networking of knowledge, experiences and experts, advanced research, development and dissemination capacity.

5. ECO-CULTURE PLANNING

The vitality of an ecosystem depends on its self-regulating ability. A natural ecosystem optimizes its function through competition, symbiosis, and natural selection while an artificial ecosystem, such as a town in a centralized planned economy, regulates its function through government planning and chain-link administration. The lack of self regulation in an artificial ecosystem often leads to erroneous decision making.

Town administrators, used to cause-effect reasoning and mono-objective management methods, attempt to manage a complicated ecological network through a simple chain-linked institution. They don't or can't understand and manage the effects of time-lags, regional impacts and information feedback of a dynamic, diversified, and large scale ecosystem. Furthermore, they often remain in a given position for only a few years and have only a limited responsibility in their own work. These circumstances illustrate the need to develop a heuristic instrument of self-learning for decision makers to help them understand their system, learn its dynamics and cybernetics, and find an appropriate way of leading the human ecosystem towards ecopolis.

The eco-culture is to build an ecologically sound and historically continuous culture in the area of cognition (philosophy, science, education); paradigm or norm (religion, legislation, morality); arts (literature, aesthetics, music); behavior (production and consumption mode, customs); tangible form (architecture, landscape, products); institution (system, organization,) and mindware (consciousness, believing, values).

Ecologically speaking, the "modern" society is a somewhat inefficient, immoral, unhealthy, counter-cybernetical and less ecologically viable habitat. Its efficiency of resource using is much lower than that of a natural ecosystem. It exploits resource through degradation of hinterland ecosystem and imposes environmental impacts on

its surroundings. Its people are estranged and competitive rather than intimate and cooperative. Its artificial living and working environment is far away from the real needs of human health. People more and more rely on electricity, water, car and chemicals to survive themselves, more and more depart from nature.

In order to jump out from this ecologically decaying culture, a refinement of people's concepts, thoughts, values, manners, emotions, tastes, customs and habits should be encouraged. And an eco-cultural revolution in production mode, life style and consumption behavior is necessary. Only when the life style is harmonious with nature in metabolism process, structural pattern and functional development, and human activities are enhancing rather than depleting the life supporting system, that a sustainable development is expected to be realized (Wang, Zhao and Ouyang 1996).

Institution and legislation reform, professional and vocational education, and national and international networking are the focus to cultivate and disseminate eco-culture for every government agencies, companies and families in the island.

6. HAINAN: FIRST ECO-PROVINCE IN CHINA

Hainan Island is the second largest island in China with 34,000 km^2 land and 7.5 million population. It locates at the south China's sea between Hong Kong and Viet Nam. While the tropical and subtropical forestry and rich biodiversity are famous, its economy is less developed and left behind most of the coastal provinces in China. In order to implement the China's Agenda 21 and find an alternative way of sustainable development, a concept of ecological province was push forward by the local government together with researchers from Chinese Academy of Sciences. The central task of eco-province development is to encourage a kind of economically productive and ecologically efficient industries, a kind of systematically responsible and socially harmonious culture, and a kind of physically beautiful and functionally vivid landscape.

A physical and social eco-assets assessment of the 18 administrative counties/cities has been carried out on the Island. The physical assessment includes standing biomass, forest coverage, biodiversity, soil organic matter, water resource potential, climate and scenery. The anthropocentric assessment includes technology, institution and people's capacity. The result shows that the physical eco-assets abundance of Hainan Island was greatly reduced since 1950s. For example, the primitive forest coverage has dropped from 35% in 1950 to 7.2% in 1987 and to only 4% or so now and it has become increasingly fragmented. The crown coverage in 58% of these forests has been shrinking from 0.8 in 1950s to 0.4-0.5 now. Within 50 years, 200 species are in danger of extinction, the mangrove area has been reduced by half, and the size of coral reefs and undeveloped coastline have been reduced by 55.5% and 59.1% respectively. The fishing resource along the coast has been degraded and 14 species have disappeared. Since 1984, the declining trend is slowing down and partly inversed in some regions when the province government took a series strategies for forest conservation. The provincial forest coverage has increased from 38.3% to 51.5%. While the social eco-assets abundance has been

greatly enhanced since 1978 especially after the Island separated from Canton as a special economic developing province in 1989.

An ecological zoning was carried out according to natural and human ecological principles, which divide the province into four functional zones:

- Ocean ecosystem around the island with an area of more than 2 million km^2, which will be the main resource for next century's prosperous of the island. A more sustainable ocean resource exploitation and efficient ecosystem conservation are necessary. The main work of the eco-development in the coming years is to enhance the research and development for ecologically sound high-technology incubation.
- Coastal aqua-terrestrial ecotone consists of estuary, beach, mangrove, coral reef, coconut trees, forestry belt around-the-island. This is a fertile and fragile region and critical in nature's conservation subject to severe deterioration. To let people understand its ecological function and spontaneously protect it is a main task for the sustainable development in this area.
- Densely populated rural and urban ecosystems characterized by intensive industrial and agricultural production. Most towns and cities of the island locate in this area. To encourage the eco-industry and ecopolis development, and strictly control the decentralized industries in rural area. The sewage treatment, for example, for hundreds of small scale and extensively distributed rubber and sugar factories all over the island, is encouraged to use ecological engineering rather than environmental engineering to reduce the costs and reuse the water.
- The rain forestry ecosystem in the central mountain area has the eco-service function of water containing and supply, biodiversity cultivation and landscape conservation. It is the sensitive region for resource exploitation and the critical region to support the whole island's life surviving and social-economic development. To increase its natural forestry coverage, to enhance capacity building of the 1400 km^2 natural reserve areas, and to prevent the area from overexploitation are the main tasks of this zone.

An eco-network analysis was carried out including

- Watershed network: Nandujiang river, Changhuajiang river, Wanquanhe river etc.
- Highway network: East, West, and Central
- Administrative network: 18 counties and cities, agriculture and industrial linkage
- Cultural network:
- Artificial landscape: eco-building, eco traffic network

Three kinds of eco-industry have been planned for the island:

- Resource based industry: tropical climate based agriculture, oil and gas based green chemical industry, and sea resource based food and pharmaceutical industry
- Tourism induced industry: eco-tourism industry, industry for tourism goods and facilities, eco-real estate industry, training and education industry
- Knowledge based industry: high-tech information industry; eco-industry transferring, consultation and incubation; market information service; and

cultural products industry.

The possible industrial development was divided into three categories:

- Kind A: those ecologically unsustainable development which are forbidden in Hainan no mater it is profitable or not, such as the decentralized heavy polluted rural industry;
- Kind B: those ecologically tolerable and economically favorable development such as the centralized high-tech heavy chemically industry which might be less sustainable but socially and environmentally feasible; and
- Kind C: those ecologically and economically sustainable development such as the ecological engineering of sugar and rubber industry which are at utmost priority of industrial development.

A strategic eco-industrial development plan has been compiled. It prepared a red list for kind A industry, and a green list for kind C industry, while most current industries which have to go the middle way as that of kind B will be gradually induced or transformed into kind C. Eco-industrial parks and an eco-industry incubation base have been initiated at Machun and Qiongshan.

Value change and capacity building are the key for ecologically vitalized culture. A main driving force of this transition is the introduction of modernization experiences of western industrial societies. While bringing advanced technology and economic prosperity to China, the western modernization has also been leading to social disintegration, marginalization of rural industries and ecoscape or Feng-Shui deterioration. Chinese human ecological tradition is being displaced by the western style of living and production. The reductionism is substituting holism, diversified human ecosystem is being substituted by mono-production and monoculture, self-reliant life style is being substituted by modern life style characterized by high-energy consumption and high environmental impacts. Individual man is becoming more and more lazy, stupid, greedy and incompetent. To meet the challenge, an ecological revolution in production mode, life style and consumption behavior is necessary.

The eco-culture is to build an ecologically sound and historically continuous culture in the area of cognition (philosophy, science, education); paradigm or norm (religion, legislation, morality); arts (literature, aesthetics, music); behavior (production and consumption mode, customs); tangible form (architecture, landscape, products); institution (system, organization,); mindware (consciousness, believing, values); and health (Qi-gong, exercise, health care, Chinese medicine).

Hainan government has set up a steering committee and an eco-province coordinating office led by a vice governor. They put the emphasis on institution and legislation reform, professional and vocational education, and domestic and international networking to cultivate and disseminate eco-culture for every government agencies, companies and families in the island.

An ABC brochure of eco-province development was distributed to government officers, industries and families in the island. Several NGOs have been set up for promoting the strategic eco-province plan including the Hainan Society of Eco-culture. Hundreds of training courses and lectures on eco-province development have been provided or planed for different trainees from governors, mayors to

ordinary citizens. A new College of Ecological Development will be built in Hainan to train local decision makers, entrepreneurs, teachers and researchers.

Eco-culture is encouraged and embodied especially in the eco-tourism development of the island. Some pilot studies have been initiated at Nanshan, Wenchang, Qionghai and Boao to cultivate Chinese culture (a combination of Confucianism, Taoism, Buddhism and other diversified culture), the native Ni and Miao minority culture and the ecological culture. The eco-culture is expected to be enhanced in the eco-cities, eco-counties, eco-villages, eco-enterprises and eco-communities development. 18 pilot eco-village selected from each counties of the whole province, and some eco-city developments are being programmed by local people together with researchers and technicians from outside.

7. YANGZHOU: OLD TOWN RENEWAL TOWARDS ECOCITY

Yangzhou city locates in the middle of Jiangsu province, and the join of the Grand Canal and Yangtze river having 4.47 million, 6638km^2 and a 2500 years history, and was known as the first state in the reaches of Yangtze River. Due to the dramatic change of urbanization and industrialization has taken place in Yangtze Delta especially at the south bank of Yangtze River along the Suzhou-Wuxi-Changzhou corridor, to catch up with the development speed while avoiding the heavy environmental pollution and ecological deterioration, Yangzhou city decided to find an alternative in implementation of China's Agenda 21 and made out their own agenda, say the outline for ecocity planning in 2000 and put it into implementation.

Eco-city development is a healthy process towards sustainable development within the carrying capacity of local ecosystem through changing production mode, consumption behavior and decision instrument based on ecological economics and system engineering. The key for its planning is an ecological integration to make trade off between economic wealth and environmental health, between material and spiritual civilization, between natural and human eco-cybernetics. Integration, demonstration, citizen's participation and scientists and technician's catalyzing are the key instruments for implementation the ecocity plan. There are three Goals of Yangzhou Ecocity Development:

To promote economic transformation from traditional economy into resource-type, knowledge-type and network-type sustainable economy with high efficiency. To make Yangzhou economy flourishing with ecological industry as forerunner;

To promote regional eco-environment to develop toward ecosystem with virescence, cleanness, beauty, vigor and sustainability. To create a good ecological basis for social and economic development;

To promote the conversion from local people's traditional production and living style and values into kind-environment, high-efficient-resources, harmonious-system, harmonious- society ecology culture. To bring up a new generation of constructor with culture, aspiration and high quality for eco-society.

The city decided to reach following short-term goals within 5 years: create 250 thousands employment opportunity, increase average education years of citizens by

10%; incubate 10 large eco-industry groups, 100 enterprises with eco-culture, the GDP annual growth rate reaches to 8-10%; recovering 1000 hectares abandoned mine areas and wetlands, set up one natural conservation area, activating and purifying 200 kilometers river, greening space in city and towns increased by 10%.The general framework is shown in Fig.3.

There are three stages in its implementation:

- *First period (2000-2005):* structure adjustment; infrastructure construction; construct basic facility; prior projects initiation; first fruits of pilot projects. Integrative power, including social power, economical power and environmental power, is on the top of Jiangsu. Primary indexes of eco-development can meet the standard of national eco-development pilot zone stipulated by National Environmental Protection Agency.
- *Second period (2006-2010):* Key pilot districts construction (cities and towns, ecological villages, factories, farms and landscape areas) and key eco-projects are achieved and the experiences are extended in the whole region. Key industries (eco-tourism, eco-agriculture, eco-construction, eco-communication, and eco-food) increase greatly. Some key products (eco-food, tourism product) enter international market. The whole city, an essential eco-city, becomes one of the most advanced cities with comprehensive social economic and environmental power in China.
- *Third period (2011-2020):* urbanization of rural area, modernization of city and ecologinization of society are achieved. The comprehensive social economic and environmental power of Yangzhou get the advanced level in the world.

Up to now, 4 national pilot ecological counties have been approved by CEPA: Baoying, Jiangdu, Gaoyou and Yizheng; Five key ecological districts have started their ecological development: ancient historical town renewal, eco-buffering area along Yangtse River (dyke areas and wetland), wetland and human ecological restoration along the Grand Canal corridor; Eco-tourism area around the Shugang-Shouxihu lake, and aforestation area at Tianshan-Gaoyouhu Lake. Five typical eco-towns of Shaobo, Dinghuo, Guazhou, Yangshou, Fanshui. Ten typical eco-village 10 eco-villages selected from 103 towns have been identified to carry out demonstrative projects for local agenda 21. Five ecological corporation groups, including eco-food, eco-communication, eco-construction, clean energy and virescence and beautification are being formed, and their gross yield will exceed 60% of the gross output value of industry and agriculture. Five capacity building bases are being set up including eco-industry incubation base, eco-products demonstration base, eco-cultural training base, eco-engineering base and eco-information and consultative network. 32 priority projects for eco-development have been approved.

A serious of capacity building measures from institutional, legislative, technical, educational and financial and safeguards have been made and put into implementation. Some domestic and international cooperative projects were initiated including a GTZ project of “Ecocity planning and management” supported by German government.

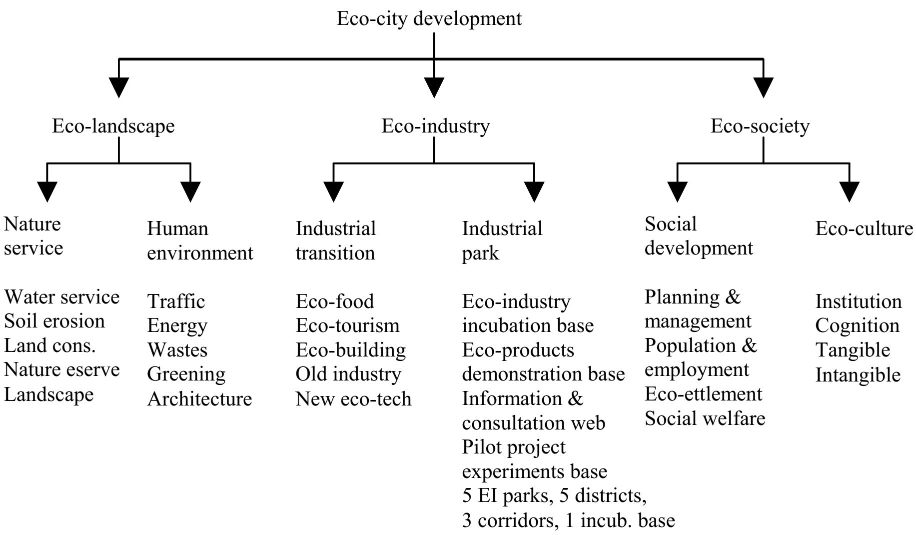

Figure 3. Structural framework of Yangzhou Ecocity development.

8. CONCLUSION

Efficiency, equity and vitality are the three dominating agents in sustainable development. Its main driving forces are energy, money, power and spirit. Competition, symbiosis and self-reliance are the main mechanism to maintain the sustainability. The key instrument for Ecopolis planning is eco-integration in total metabolism of material and energy; total cultivation of eco-industry, ecoscape and eco-culture; total coordination of system contexts in time, space, quantity, structure and order; total design of development goals in wealth, health and faith; total cooperation between decision makers, entrepreneurs, researchers and the publics.

Sustainable development requires systematically responsible planning, totally functioning design and ecologically vivid management, which combine hardware, software and mindware into a integrative implementation system, and encourage bottom-up and flexible rather than top-down and rigid institution, and helping local people to help themselves through capacity building.

An ecologically sound planning should help local people to set up a vision about how the ecoscape is coupling, functioning and vitalizing systematically and ecologically, and how their action is connected with their social, economic and long term ecological interests.

9. ACKNOWLEDGEMENT

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10. REFERENCES

Wang, R.S. and Ouyang, Z.Y. 1996. Ecological integration: the methodology of human sustainable development, *Chinese Science Bulletin* 41: 47-67.

Wang, R.S., Zhao, J.Z. and Ouyang, Z.Y. 1991. *Human Systems Ecology*. China Science and Technology Press, Beijing. 240pp.

Ma, S.J. and Wang, R.S. 1984. Social-Economic-Natural Complex Ecosystem. *Acta Ecologica Sinica* 4: 1-9.

Wang, R.S. and Yan, J.S. 1998. Integrating Hardware, Software and Mindware: Ecological Engineering in China, *Journal of Ecological Engineering* 11: 277-290.

Wang, R.S., Zhao J.Z. and Ouyang Z.Y. 1996. *Wealth, Health and Faith, -Sustainability Studies in China.* China's Science and Technology Press, Beijing.

Wang, R.S. and Qi, Y. 1991. Human Ecology in China: Its Past, Present and prospect, In S. Suzuki (Ed.), *Human Ecology Coming of age: An International Overview* (pp. 183-200). Free University Brussels Press, Brussels.

Wang, R.S., Yang, B.J. and Lu, Y.L. 1991. Pan-Objective Ecological Programming and Its Application to Ecological Research. In P. Korhonen, A. Lewandowski and J.Wallenius (Eds.), *Multiple Criteria Decision Support, Lecture Notes in Economics & Mathematical Systems* (pp. 321-330). Springer-Verlag, Berlin.

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YUKIHIRO MORIMOTO

CHAPTER 20

ECOLOGICAL DYNAMICS OF URBAN AND RURAL LANDSCAPES - THE NEED FOR LANDSCAPE PLANNING THAT CONSIDERS THE BIODIVERSITY CRISIS IN JAPAN

1. INTRODUCTION

Drastic changes have occurred in the Japanese landscape since the Second World War because of urban sprawl, the energy revolution in agricultural communities and modernization of agricultural production systems. In mountainous areas, the national park system has played a major role in protecting natural values. However, a survey of endangered species has revealed the increasing importance of the countryside and the urban fringes. Within urban areas in Kyoto, which is surrounded by mountains, a useful analysis and a planning tool is that of island biogeography, where green areas are considered to be islands in an 'ocean' of built-up areas. We are facing a difficult task to maintain biodiversity in rural areas, where the diverse and cultural small ecosystems once associated with traditional land use have been destroyed.

Themes of nature restoration in Japan have also changed as a result of the recognition of the biodiversity crisis. Development of adaptive management techniques will be needed both in urban and rural landscapes. Nature restoration in urban areas, where wetlands and forests once existed, is another important task for the ecologically sustainable city. Landscape ecological concepts relevant to landscape analysis, planning and implementations, based on several examples in Japan, are discussed.

2. CRISIS OF BIODIVERSITY AND WILDLIFE HABITAT IN JAPAN

Recently, the Japanese Ministry of Environment published a Red List of Japanese plants and, subsequently, other Red Lists. These lists are based on the categories proposed by the International Union of Nature Conservation (IUCN), such as critically endangered (CR), endangered (EN) and vulnerable (VU). The Japanese Ministry of Environment developed the original method to evaluate the species extinction probability of trees and plants for the purpose of fulfilling the requirements of the IUCN categories.

As a result, 7000 species are recognized as the number of taxa to be evaluated. Of these, 20 species have proved to be already extinct, and 23.8 percent of the

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Japanese flora is listed as endangered or vulnerable. It was extraordinary to see that those listed as vulnerable include two of the seven common autumn plants in Japan, 'Kikyo' (*Platycodon grandiflorum*) and 'Fujibakama' (*Eupatorium fortunei*). These are very popular throughout Japan. The recognition of the crisis of species extinction, which was known only to a limited number of specialists before the survey, has come to be widely recognized, not only by the results on plants but also by the results for insects, mammals and amphibians.

We can illustrate the crisis by consideration of two groups of endangered species. The first group is composed of those rare species where their distribution was originally limited to small areas such as islands and high mountains. The importance of protection for such species has been widely recognized. The second is comprised of originally common species, distributed in secondary forests, agricultural fields, wetlands, grasslands and coastal areas, including shallow seas. Most of these areas are alluvial plains or hillsides and their surroundings where cities and agricultural fields exist. No matter how strictly we protect the mountainous areas, we cannot mitigate the crisis of biodiversity in those areas where human activity is dominant. An exception is the Shinodayama wetland (Morimoto 2003), because this area has been a training field of the Japan Self Defense Forces. Here the disturbance by man had prevented plant succession to forests and maintained the group of small spring-fed wetlands and grasslands. On the basis of these Red List investigations, the Japanese government established 'The new strategy of biodiversity conservation' in March 2002. One of the notable features of the new strategy, which is a revised version of the strategy of 1995, is that it recognizes three types of biodiversity crises.

The first type is caused by the destruction, fragmentation and isolation of wildlife habitat. In Japan, this was very severe during the high-growth period of the 1970s and the so-called the 'bubble economy' period of the late 1980s. Currently, this kind of crisis is less severe, although development pressures continue to impact on islands, tidal flats near urban areas and Satoyama (the traditional rural landscape).

The second type is caused by the loss of sustainable habitat for nature owing to the change of agricultural production systems and human lifestyle in the countryside (Washitani 2003). The mosaic structure of the Satoyama landscape, which includes terraced paddy fields, secondary forest, irrigation ponds and other land uses, provided a useful habitat for wildlife but is being lost.

The third type of crisis is the negative impacts of introductions by human beings, introducing both introduced species and chemicals. Some of these have caused severe threats to native species and have disturbed native ecosystems.

The first type of crisis had been long recognized, and one of the major objectives of the Environmental Agency of Japan was to protect natural areas by establishing the national park system and nature conservation areas. The policy has functioned successfully in the primitive areas where it was applied.

On the other hand, the second type of crisis, revealed through the investigations necessary to draw up the Red Lists, is the major concern of the present. The loss of adequate availability of the natural elements of the Satoyama areas has caused a crisis for disturbance-dependent species. Examples include alterations in plant

succession when changing from deciduous coppice forests with high biodiversity to evergreen forests with limited numbers of shade-tolerant species, plant successions in grasslands by reduction of mowing and pasturing, and modernization of agriculture from terraced, wet paddy fields with traditional management (*e.g.*, irrigation waterways with no lining) to well-drained dry paddies with pipelines or concrete waterways. Moreover, quite a few weed species once controlled in paddy fields have come to be listed as endangered because of restructuring of fields for modern agriculture.

The third type of crisis shows the need for consideration of the plant materials that were used for nature restoration in disturbed areas. Until recently, many introduced grass species and leguminous species were used for the purpose of revegetation of artificial slopes. Problems resulting from this include the driving out of native species by escaped introduced species in dry riverbeds, genetic pollution of endemic species by crosses with closely related non-native species, and so on.

3. LANDSCAPE ECOLOGICAL THEORIES FOR FRAGMENTED HABITAT PLANNING IN JAPAN

While urban areas have few features in common with natural ecosystems, urban areas cannot ignore natural processes. We cannot fully control physical processes such as radiation and wind or biological processes such as colonization, propagation and extinction. Recently, landscape ecological analyses and proposals have become important issues in city planning - how to deal with nature in urban areas, with consideration for the contributions of wildlife habitats to the urban environments. Contributions of landscape ecological concepts to planning and management of city development, based on several studies of wildlife habitats in Japan, are discussed below.

3.1. Patterns

Ecosystem ecology is the analysis of the structure and function of typical communities. A lot of knowledge has been accumulated about each of these rather homogeneous ecosystems. Landscape ecology, in contrast, deals with land mosaics with various heterogeneous elements. One of the major viewpoints of landscape ecology is the patch corridor-matrix concept to deal with the fragmented distribution of ecosystems at landscape scale.

In primeval parts of Japan, most landscapes may be interpreted as a matrix of forest with a few patches of non-forested areas, such as open areas caused by typhoons, landslides or other natural disturbances, and river corridors. In urbanized areas, the landscapes may be interpreted as built-up matrices with preserved urban woodlands and park patches that are the main habitat of wildlife, and corridors such as rivers and streets. Urbanizing processes such as the perforation, fragmentation and isolation of greenery could be regarded as habitat degradation from the viewpoint of forest biodiversity. Such processes could also generate increased areas of forest edge habitats, with the particular characteristics of such an environment (where active production, colonization and regeneration processes occur). Such

processes are rare in closed-canopy forests. As a result, the response of organisms and species diversity to habitat fragmentation shows unique characteristics.

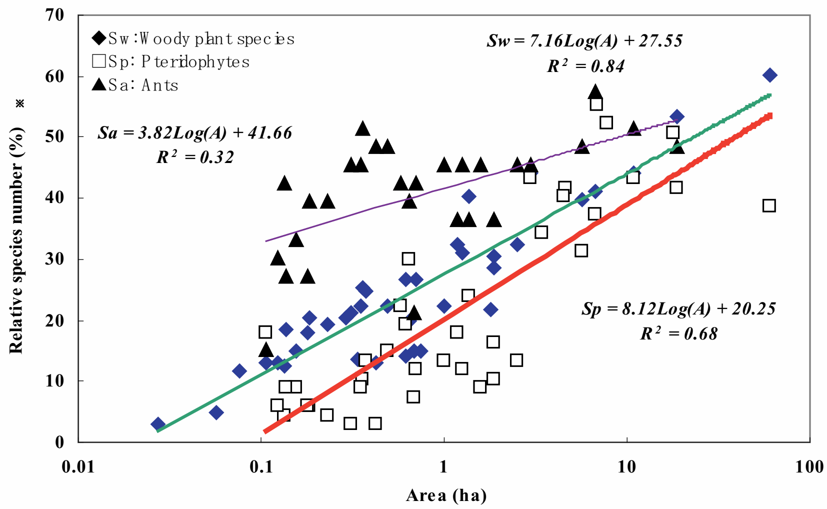

Figure 1. Species-area relationship of woody plant species (Murakami and Morimoto 2000), Pteridophytes (Murakami et al. 2003) and Ants (Yui et al. 2001) in fragmented forests in Kyoto city. Relative species number means the ratio of the numbers of that species to the total number of species found in all fragmented forest patches.

Several observations in the city of Kyoto are shown in Figure 1. Woody plant species respond to the patch size most clearly. The species richness of ants has a relatively weak response to the patch size and depends strongly on microhabitat diversity (Yui *et al*. 2001); such features as soil surface conditions, the existence of fallen tree trunks, etc. On the other hand, as pteridophyte (fern) species generally response to micro-relief, the species diversity is affected also by the microhabitat diversity. As the shrinkage of a forest patch size in an urban area may result in a drier environment, making the habitat for ferns very severe, the slope of the regression line in the area is steeper and wider-scattered than the line is for woody plants.

3.2. Process in Urban landscapes

It is well known that MacArther and Wilson (1967) explained the species number in islands distributed in the ocean as the result of two processes, colonization from the continent and extinction. The probability of colonization is a function of distance from the continent and the probability of extinction is a function of the area of the

island. This famous theory of island biogeography is sometimes applied to the biodiversity in city areas.

The species richness of breeding birds by landscape-level factors in urban woods in Osaka (Natuhara 1999), including quite urbanized area as well as surrounding mountains with forest cover, showed clearly the effect of the tree cover ratio in the city and the distance from the mountains. The Great Tit (*Parus major*), an insect-eating forest bird, is a good indicator both of urbanization and of an ecologically healthy city. Several studies, such as that of Hinsley *et al*. (1999), point out the dependence of this species on the area of forest. In the city area of Osaka, one of the most densely populated areas in Japan, Hashimoto (2002) and Hashimoto *et al.* (2002) examined various land cover properties that may determine the habitat quality for the species. They developed a habitat model using logistic regression that implies only two significant parameters, the tree-covered area within a radius of 250 m, and other habitats of Great Tit within a 1 km buffer. The former shows the property of the habitat itself, and the latter has a relation to the process.

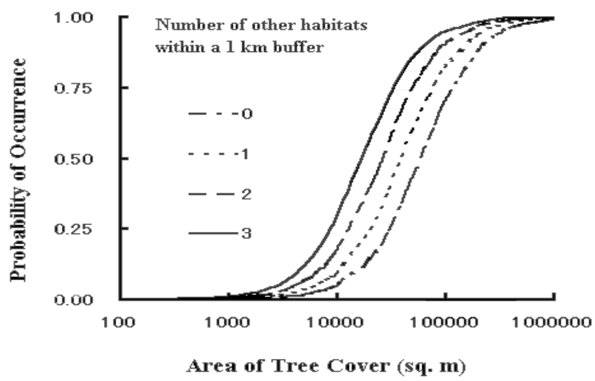

Figure 2. Logistic regressions of the probability of Great Tit occurrence and the area of tree cover within a radius of 250 m and the number of other habitats within a 1 km buffer.

We examined several species groups, including woody plants (Murakami and Morimoto 2000), ferns (Murakami *et al*. 2003), ants (Yui *et al*. 2001) and birds (Hashimoto *et al*. Unpublished) in the city of Kyoto, which is surrounded by mountains covered with forests. Mountains are regarded as the continent, built-up areas as the ocean and isolated woods as islands. Then the following expression describes the number of species present in isolated woods, or islands:

$$S_S = I\,P\,/\,(E + I) \qquad (1)$$

Here S_S i represents the species number in equilibrium, P the species number in the continent, I is the colonization rate, and E is the extinction rate. The colonization

rate, I, is a function of the distance from the continent, and is generally in inverse proportion to P, and E is a function of the island area.

Following this theory, a larger forest patch is expected to support more species than a smaller one. The greater the value of IP, the continental species that colonize the islands, the greater is the species richness in isolated forests in urban areas.

A meta-population model can be applied to the processes of colonization and extinction in isolated patches distributed in urban areas. The ratio of patches occupied by certain species to total patches, p, is expressed by following formula;

$$p = 1 - m / c \tag{2}$$

where c is the generation rate and m is the disappearance rate. Here, regarding c as the colonization rate and m as the extinction rate, we can analyze the processes in fragmented and isolated wildlife habitats. Although it is a very simple model, we can use it to evaluate development and conservation scenarios in fragmented habitats. The precise values of viability for target species may not be determinable, but the values which are obtained are useful to highlight the key points in each scenario.

Natuhara, Miyoshi and Morimoto (2002a) applied the theory to evaluate the impact of city development projects on rural landscapes using population viability analysis of the clouded salamander, *Hynobius nebulosus*. This salamander depends on small ponds or paddies for laying eggs and for larva development, and the adult lives in the adjacent forest floor litter. Therefore, as a Yatsu, a landscape unit of terraced rice paddies and surrounding forests, is the suitable habitat for the salamander, this species has become vulnerable not only to development but also to abandonment or modern restructuring of paddy cultivation. Scenarios studied (Natuhara *et al.* 2002a, b) on a development project in a Satoyama with Yatsu, near Kyoto City, and evaluated by meta-population viability analysis showed the importance of the connectedness of preserved forests remnants and the effectiveness of creating several ponds. It is no surprise that ordinary development plans, which completely alter the original landscape, form a very bad scenario for conservation. However, it is very significant that the worst scenario for the salamander's viability is the modernization of rice paddies, which eliminates egg-laying spots.

Another important suggestion of the meta-population theory is that vacant patches are inevitably produced unless m is very small or c very large. Thus the theory implies the potential benefits of forest patches, even though these may be currently devoid of a certain species.

From the viewpoint of plant communities, potential vegetation depends mainly on the physical environment, which could be evaluated mainly by climate and soil type (which itself is related to geology, topography and weathering processes).

To enhance the conservation values of areas of degraded vegetation and the wildlife that are dependent on it, we should consider not only protecting the existing vegetation but also restoring it to its potential. At the landscape scale, where it needs very intense efforts to get precise distribution data of fauna, potential habitat analysis is convenient.

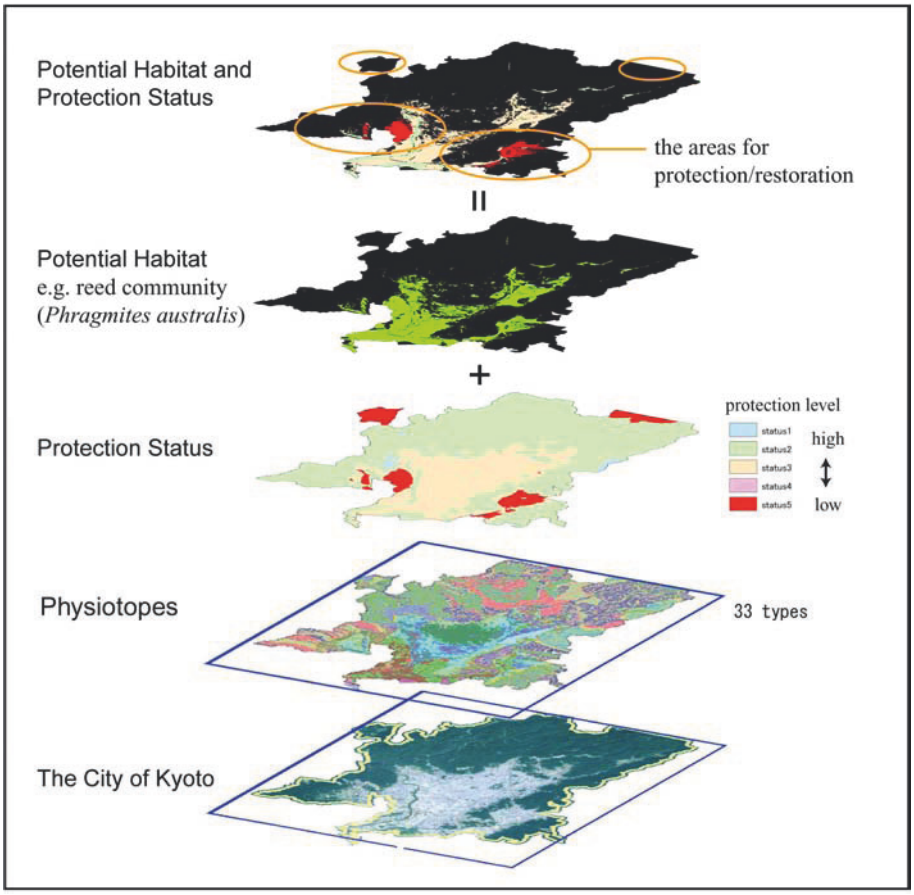

Figure 3. Gap analyses using potential habitat to identify the areas for protection and restoration in the city of Kyoto (Imanishi et al. unpublished). Potential habitat for each vegetation was estimated using 33 physiotope classes and existing locations. The figure shows the case of reed community, one of the remarkably reduced communities. Potential habitat overlaid with protection status could help us to identify the areas not only for protection but also for restoration. (See Color Plates, p.xxi)

Imanishi *et al*. (Fig. 3) applied potential physiotope evaluation to estimate potential vegetation for the gap of conservation action (GAP) analysis of Kyoto City area and its surroundings.

In order to bridge the gap between conservation action and observation of ecological importance, it is necessary to identify areas which are candidates for more conservation and also those which are candidates for restoration. Because conservation efforts confined to fragmented habitat run a higher risk of species

extinction, such potential habitat analysis is needed for restoration planning of wildlife habitat.

The application of island biogeography and the meta-population model provides and interesting tool for urban and rural landscape planning where wildlife habitat conservation is to be considered.

4. ECOLOGICAL URBAN GREENERY PLANNING AND THE GREENWAY THEORY

From an ecological viewpoint, seashore and river corridors, including seaside and riparian vegetation, are very important for maintaining biodiversity. These ecotones have two main features of value: belt-like ecosystems play the role of an immigration route for wildlife, and such corridors produce a water-land ecotone, which is essential for many species that need two different resources. The ecotone, the transition zone where two different land-covers meet, is important not only for wildlife but also for human culture.

The city of Kyoto is situated in a flat basin surrounded by forested mountains (Fig. 3) to the west, north and east. At the foot of Higashi-yama (the eastern mountain), an ancient footpath goes through the transition zone between paddies and mountains, continues directly northward along the Hanaore fault to Obama city, facing the Japan Sea. This ancient road was called the Mackerel Road because it was used for the transportation of marine products to Kyoto, the capital city at that time. Faults are very convenient to use as roads in mountainous regions, because of they tend to go in a straight line, and almost all of the ancient roads depend on faults. Many cultural assets are found along the road including the Shugaku-in imperial villa, and the temples Manshu-in and Ginkaku-ji. Thus geology and topography have a strong influence on the belt-like distribution of cultural assets.

In the Meiji period (1867-1912), the outstanding works by Jihei Ogawa, who was a great innovator of the Japanese garden, began at the foot of Higashi-yama. Although he created many gardens – not only in Kyoto but also throughout the whole country – the gardens created here at the foot of Higashi-yama show the most typical characteristics of his art. Examples include Murin-an, Shokuho-en and Hekiun-so. The gardens take advantage of 'borrowed scenery' from surrounding mountains, streams and ponds that had become available by the construction of the Lake Biwa canal, open spaces of lawn and wandering paths through nature-oriented design. The second Lake Biwa canal, which goes up along the foot of Higashi-yama, could add new resources to the existing ecotone. Evidence of the commonality of culture and biodiversity is the rich fish fauna in his nature-oriented garden ponds and streams, where even one of the endangered species in Lake Biwa, the water source of the canal, is inhabited (Ito and Morimoto 2003) The stream-pond system of Heian-jingu garden could be regarded a refugium for wildlife.

Greenway theory has its root on the so called Emerald Necklace, a park system in Boston proposed by F. L. Olmsted more than a hundred years ago, which includes the waterside ecotone of Back Bay Fens and a riverside walk with greenery. It is very interesting that the outstanding works of the same age have become revalued

by their ecological role as ecotones and corridors. The setting of a belt-like conservation area considering ecological corridors is an important theme of urban greenery planning.

5. CHANGING THEMES OF NATURE RESTORATION IN JAPAN

Intensive efforts in nature restoration in degraded mountains and artificial slopes in Japan began a hundred years ago at the Rokkoh Mountains (this was regarded, by Admiral Perry's American mission that came to Japan to call for open trade, as an iceberg because the naked granite mountain was as white as ice!). Erosion control, planting of pine trees on terraced slopes, planting trees to enrich the soil, and other techniques could help the degraded mountain restore its productivity.

Many development projects, of roads and housing lots, in mountainous Japan during the period of rapid economic growth from 1960-80, created slopes that required erosion control. This is the reason for the remarkable development of technology for rapid revegetation. Grassland can be established even on bare rocks by the growth-media spraying method. However, it was around 1980 that many problems, with the rapid revegetation technology became obvious from the viewpoint of the essential goal of nature restoration. The more success that was achieved by rapid coverage with exotic grass species or leguminous species, the more difficulty found in growth or recruitment of tree species expected to form the forest which was hoped would form the final vegetation. Thus a new policy for revegetation technology emerged: how to establish forest using indigenous species. This was adopted not only on artificial slopes but also many planting projects, such as large-scale green belt around factories. The method involved planting seedlings in high density with enough soil amendment to establish forests native to the target area. This method was called 'ecological revegetation'. However, results of monitoring this showed a biased succession with few shade-tolerant tree species and a dense monoculture of forest, which in turn led to an impoverished fauna (Natuhara *et al.* 1999, Yui *et al.* 2000), including a decrease in species assemblages of ants, butterflies and birds.

The Nature and Culture zone of the EXPO'70 Commemorative Park is an epoch-making forest restoration project which intended to restore indigenous forests on the ground reclaimed after the EXPO. This was the first opportunity to establish indigenous forests on a large area of completely disturbed ground. From 1972 to 1976, land grading and tree planting was carried out on about 100 ha. Intensive monitoring (Njoroge *et al*. 2000) of the forests about 10 and 25 years after planting revealed the important role of the soil properties on the forest growth and biodiversity, and also revealed the same problems as had occurred with ecological revegetation. Morimoto (2003) concluded that the problem is because the even-aged young forest community lacks heterogeneous properties at both a forest-stand scale and also a landscape scale.

Figure 4. Comparison of EXPO'70 site in 1970 (left) and 2000 (right). Reclaimed and afforested in 1972-76 under the concept of a self-sustaining forest ecosystem in the urban area. (See Color Plates, p.xxii)

Figure 5. Comparison of initial (left) and one year after (right) the management treatment of patch thinning and soil seed bank introduction from the nearest remaining forest. (See Color Plates, p. xxii)

As he pointed out, two major landscape ecological issues to be considered are, firstly, limited natural disturbances in a controlled environment tend to lead a monotonous landscape and, secondly, the EXPO forests are isolated from sources from which colonization of other flora and fauna might occur. To enhance the biodiversity of the forests, an adaptive management method (the 'second generation forest project') was started, to include patch thinning and introduction of seed sources to make the landscape heterogeneous. The project gave a positive result (Nakamura *et al*. 2002) with respect to the butterfly assemblage and vegetation within a year after commencement.

Increasing interest has been given to the restoration of wildlife habitats in urban areas for more than ten years. Kyoto city created an urban park in the heart of the city where there was once a large stockyard of freight trains. A little less than one hectare of this park was designed for wildlife habitat restoration; this is the first case of habitat restoration in Kyoto city and is also a rare case of nature restoration in the downtown area of a city in Japan. In the planning process, the ecological potential of the area and the design method were carefully considered in a workshop, where the author was involved as chairman, designed to set goals for the wildlife habitat park. After its construction, an ecological monitoring project by a volunteer group, consisting of professionals and interested citizens, is continuing and six annual

reports have been published. More than 500 plant species (Morimoto 2002), including vulnerable species of the Kinki district, have been recorded. It was proved that even in the most urbanized area of Kyoto an area of less than one hectare of open space has a very high potential for nature restoration. The limitations to the potential of such sites, because of the restricted ecological network in urban areas (Morimoto 2002) are becoming clear.

To develop landscape planning, design, design implementation and management methodology considering biodiversity crisis in Japan, the ecological dynamics of urban and rural landscapes should be studied in every sense of the words 'landscape ecology'.

6. REFERENCES

Chikamatsu, M., Natuhara, Y., Mizutani, Y. and Nakamura, A. 2002. Effect of artificial gaps on the butterfly assemblage in urban woods. *Journal of Japanese Society of Revegetation Technology* 28: 97-102

Hashimoto, H. 2002. Evaluation and creation of nature in urban area from a viewpoint of Great Tits. *Master's program thesis of Graduate School of Agriculture and Biological Sciences, Osaka Prefecture Univ.* pp. 46.

Hinsley, S.A., Rothery, P. and Bellamy, P.E. 1999. Influence of woodland area on breeding success in Great Tits *Parus major* and Blue Tits *Parus caeruleus*. *Journal of Avian Biology* 30: 271-281

Ito, S. and Morimoto Y. 2003. Garden Ponds as Wildlife Habitats for Fish from Lake Biwa into Kyoto City. *Journal of the Japanese Institute of Landscape Architecture* 66(5): in press.

Kuramoto, N. and Sonoda, Y. 2003. Conserving biological diversity, In K. Takeuchi *et al.* (Eds.), *Satoyama-The traditional rural landscape of Japan* (pp. 81-89), Springer, Tokyo.

MacArthur, R.H. and Wilson E.O. 1967. *The Theory of Island Biogeography*. pp.203, Princeton University Press, Princeton.

Morimoto, J. and Morimoto, Y. 2003. Satoyama landscapes transition in the Kansai Area. In K. Takeuchi *et al*. (Eds.), *Satoyama-The traditional rural landscape of Japan* (pp. 60-71), Springer, Tokyo.

Morimoro, Y. and Kobashi, S. 1985. On the pedogenic process in the forest areas of the Commemorative Park of EXPO'70. *Journal of the Japanese Institute of Landscape Architecture* 48: 115-120.

Morimoto, Y., Nakamura, A. and Tabata, K. 2000. Feasibility of employing mitigation banking for the alleviation of the ecological impact of road construction in Japan. *10th Road Engineering Association of Asia and Australasia Conference*, paper 172, 1-8, Tokyo

Morimoto, Y. 2001. Tree planting for environmental restoration in Japan and the role of landscaping. *International Symposium on Man and Nature – Landscape, Horticulture and Plant Resources* (pp. 20-24), Kunming: Kunming Institute of Botany, China.

Morimoto, Y. 2003. *Inochi-no-Mori, Annual report of the Inochi-no-Mori Monitoring group. 6,* pp.54, World Wide Web: http://rosa.envi.osakafu-u.ac.jp/biotope/inochi6.pdf

Morimoto, Y. 2003. Wetland environments and biodiversity in the hills, In K. Takeuchi (Eds.), *Satoyama-The traditional rural landscape of Japan* (pp. 94-101), Springer, Tokyo.

Murakami, K. and Morimoto, Y. 2000. Landscape ecological study on the woody plant species richness and its conservation in fragmented forest patches in Kyoto City area. *Journal of Japanese Society of Revegetation Technology* 26: 345-350.

Murakami, K., Matsui, R., Maenaka, H. and Morimoto, Y. 2003. Relationship between species composition of pteridophytes and micro landform types in fragmented forest patches in Kyoto City area. *Journal of the Japanese Institute of Landscape Architecture,* 66(5): in press.

Nakamura, A., Morimoto, Y., Mizutani, Y., Yasui, S. and Nakai, K. 2002. Adaptive management approach to increase diversity on a 30-years old artificial forest in an urban area. *Journal of Japanese Society of Revegetation Technology* 28: 283-285.

Natuhara, Y. and Imai, C. 1999. Prediction of species richness of breeding birds by landscape-level factors of urban woods in Osaka Prefecture, Japan. *Biodiversity and Conservation* 8: 239-253

Natuhara, Y., Miyoshi, F. and Morimoto, Y. 2002a. A conservation scenario for the Clouded Salamander, *Hynobius nebulosus* using MPVA. *Journal of the Japanese Institute of Landscape Architecture* 65: 523-526

Natuhara, Y., Miyoshi, F. and Morimoto, Y. 2002b. The Effect of abandonment of paddy cultivation on the distribution of the Clouded Salamander, *Hynobius nebulosus* and preliminary test of the habitat restoration. *Japanese Journal of Environmental Entomology and Zoology* 13: 11-17.

Natuhara, Y. and Imai, C. 1999. Prediction of species richness of breeding birds by landscape-level factors of urban woods in Osaka Prefecture, Japan. *Biodiversity and Conservation* 8: 239-253.

Njoroge, J.B., Morimoto, Y. and Natuhara, Y. 2000. Using remotely sensed surface attributes to assess avian community composition in a reclaimed urban park. *10th IFLA Eastern Regional Conference '00 Proceeding Book*, pp. 179-187, Awaji.

Njoroge, J.B. and Morimoto, Y. 1999. Surface heat energy balance in relation to growth condition of urban park vegetation. *Papers on Environmental Information Sciences* 13: 61-66.

Njoroge, J.B., Nakamura, A. and Morimoto, Y. 1999. Thermal based functional evaluation of urban park vegetation. *Journal of Environmental Sciences* 11: 252-256.

Njoroge, J.B. and Morimoto, Y. 2000. Studies on soil development as influenced by the method of large scale reclamation of a sub-urban forest. *Journal of Japanese Society of Revegetation Technology* 25: 184-195.

Njoroge, J.B., Fukui, W. and Morimoto, Y. 2000. The habitat usage of vegetation types by avifauna community in the reclaimed site of EXPO'70 Commemoration Park. *Journal of the Japanese Institute of Landscape Architecture* 63: 501-504.

Yui, A., Njoroge, J.B., Natuhara, Y. and Morimoto, Y. 2000. An evaluation of the recovery conditions for reclaimed land using ant diversity. *10th IFLA Eastern Regional Conference '00 Proceeding Book*, pp. 281-288, Awaji.

Yui, A., Natuhara, Y., Murakami, K. and Morimoto, Y. 2001. Factors affecting ant diversity in fragmented forests in an urban area. *Journal of Japanese Society of Revegetation Technology* 27: 78-83.

Washitani, I. 2003. Species diversity in Satoyama landscapes. In K. Takeuchi *et al*. (Eds.), *Satoyama-The traditional rural landscape of Japan* (pp. 89-93), Springer, Tokyo,

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CHAPTER 21

ECOLOGICAL ENGINEERING FOR RESTORING RIVER ECOSYSTEMS IN JAPAN AND KOREA

1. INTRODUCTION

Rivers and streams are one of the ecosystems that have been seriously altered by means of human activities, particularly by civil engineering works (*e.g.* Bravard *et al*. 1986, Brooks 1988, Décamps *et al*. 1988). A barrage constructed near river mouth seriously changes estuarine environments (Murakami 2002, Nakamura and Fujino 2002, Yamauchi 2002). Dam construction creates a new lake ecosystem in a river with resultant discontinuity of material transportation and wildlife populations such as migratory fishes (Vannote *et al*. 1980, Mori 1999). Stabilization of river flow and alteration of sediment transportation by dams affect not only on benthic animals but also on plant species, which depend on hydraulic characteristics and hydro-geomorphic processes in a river (Tanida and Takemon 1999, Jansson *et al*. 2000, Kamada *et al*. 2002). Flood frequency and intensity have been reduced by dam operation, and it causes woodland expansion on bars (Harris *et al*. 1987, Johnson 1994, Woo and Yoon 2002). Channelization changes ecological function due to degeneration of riffle-pool structure of original rivers (Brooks 1988, Nakamura *et al.* 1997, Nagasaka and Nakamura 1999).

In accordance with the spread of social recognition for importance of biodiversity and seriousness of ecosystem crisis, social demand for restoration of degraded ecosystems has been increased (Primack 1995), and many works for restoring river ecosystems have been conducted. Scientific knowledge for management of river ecosystems has been deepened and practical works have been progressed mainly in Europe and North America (Harper *et al*. 1995, Landers 1997). Goodwin *et al*. (1997) summarized that four issues are needed to progress the restoration of river ecosystems, *i*) interdisciplinary approach, *ii*) unified framework for approaching, *iii*) understanding processes, and *iv*) considering the causes of degraded conditions. In addition in order to restore the degraded river ecosystems, it is necessary to make clear target image for restoration that should be acceptable both ecologically and socially in each region/country.

Japan and South Korea (The Republic of Korea) have a common tradition in two aspects of river management systems, *i*) disaster prevention against flood and *ii*)

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securing irrigation of paddy fields against drought, which was developed under the common climate conditions with frequent typhoon events and rice-producing cultures through more than two thousand years. Although the irrigation system had priority over flood prevention before the modern age, innovation in civil engineering and agriculture changed the river management systems too rapidly and resultant civilization accelerated degeneration of river ecosystems in both countries. In our countries, ecological engineering is at a beginning stage and scientific knowledge on the processes of river-ecosystem degeneration and methodology for solving the ecological problems in artificially altered rivers are under rapid development. In order to restore healthy river ecosystems in these countries, it is indisputably necessary to develop methodology for assessing river ecosystems based on the hydrological and historical characteristics of the countries.

Aims of the present article are *i*) to introduce scientific and practical activities for river restoration in Japan and South Korea, where natural and social systems are similar each other and different from Europe and North America, and at the same time, *ii*) to make an international bridge of the scientific field of ecological engineering.

2. NATURAL AND SOCIAL BACKGROUND OF RIVERS IN JAPAN AND KOREA

2.1. Geography

Japan and Korea are the neighbouring countries facing across the Sea of Japan/East Sea (Fig. 1). Japan is an island country that is comprised of approximately 6800 islands with four of them (Hokkaido, Honshu, Shikoku and Kyushu) making up more than 99% of the country. These islands extend over 2,000km in total length but spread only about 300km in width. The land area is approximately 377,873 km^2. Japan is 68% mountainous, about 13% is arable farmland, and 4.4% is residential areas. As of August 2001, Japan's population was counted at 127.1 million, the ninth highest in the world, and population density is 337 people per square kilometre (Embassy of Japan, 2003, River Bureau, 2003a).

Korea, including Democratic People's Republic of Korea (North Korea) and Republic of Korea (South Korea), occupies Korean Peninsula, which spans 1,100 kilometres north to south, and is comprised of 3,200 islands. The land area of Korea is approximately 221,000 km^2 and South Korea occupies 45% of the land. Almost 66% of South Korea's land consists of mountains. As of the end of 2000, South Korea's total population was estimated at 47,275,000, with a density of 476 people per square kilometre (Embassy of Korea in the U.S.A. 2003). Since early era of our histories the residents have engaged in rice cropping in the alluvial plains created by flooding rivers in both countries. Being dependent on the rivers for irrigation and drinking water as well as being vulnerable to the inevitable floods, the residents regarded the rivers as both their mentors and their rivals.

Rivers in both countries are prone to flood because of relative shortness and steepness of the slopes along their basins, the length and drainage area of the

Shinano River and Han River, which are the longest rivers in Japan and Korea, are 367 km and 11,900km^2, and 482 km and 32,000 km^2, respectively.

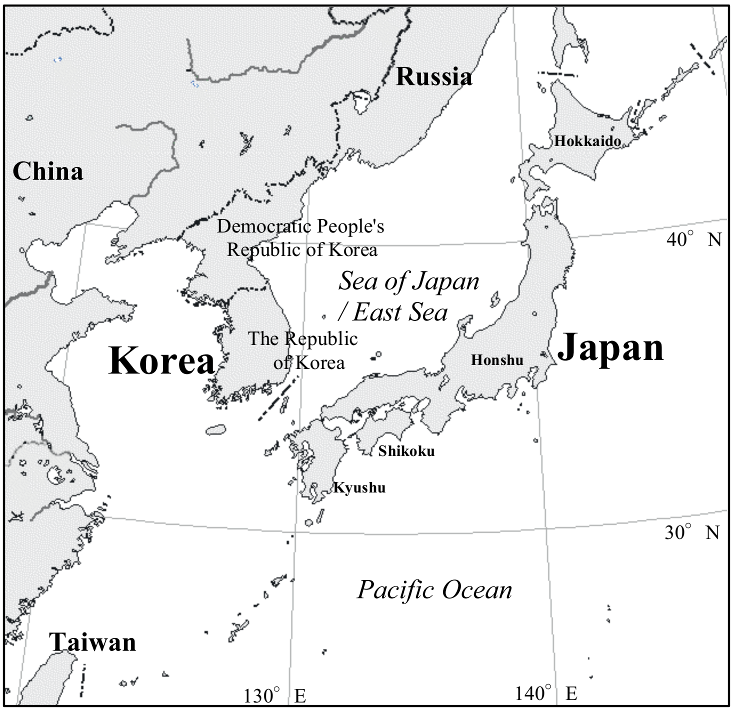


Figure 1. Location of Japan and Korea

Due to the topographical conditions and occasional torrential rainfalls, the hydrographs of the rivers in Japan and Korea are very sharp, and peak flood discharges are very large compared with the continental rivers. An average ratio of the maximum discharge to the minimum discharge of Japan's 73 major rivers in 1994 was as high as 365 with the range from 46 to 2842 (River Bureau, 2003b: rivers with the value both from the smallest to 10th and from the biggest to 10th were omitted), and that of Korean river usually ranges from 100 up to 700 (Woo and Lee 1993). These ratios far exceed those for the rivers in Europe and United States, where they are usually less than 100.

Nowadays the population density in these countries ranks as one of the highest in the world, and almost people inhabit in small areas around middle and lower reaches of rivers, in other words, the area except for the mountain have been extensively inhabited and/or used. Regarding Japan, 49% of the population and 75% of holdings are located within the flood-prone areas of rivers. Although in a less degree, Korea is in a similar situation.

2.2. *Climate*

The climate of Japan and Korea varies greatly from north to south. Regarding Japan, Hokkaido with a subarctic weather pattern, has an annual mean temperature of 8 °C, while Japan's southernmost islands belong to the subtropical climate zone and have an annual mean of over 22 °C. Annual mean precipitation varies from 900 mm to 2,000 mm in these regions. The onset of the rainy season takes place in June, and ushers in summer. The period from middle August to September is the time of typhoons with heavy rain. Annually, about 28 typhoons occur in the western Pacific, and two or three of them hit Japan on average. Winter tends to be chilly, and heavy snows can occur both in the northern island of Hokkaido and the Hokuriku region of western Honshu, which face to the Sea of Japan and have high mountains behind (Embassy of Japan 2003).

Korea has also several climate regions from subarctic to warm temperate region (Yim and Kira 1975, 1976). Variation in annual mean temperature ranges from 3.7 °C to 14.7 °C (Yim and Kim 1983). Precipitation distribution of the Korean Peninsula is mainly affected by its geographical features. The southern coastal and its adjacent mountain regions have the largest amount of annual mean precipitation exceeding 1,500mm. The sheltered upper Amnok (Yalu) River basin in the northern region, on the other hand, experiences less than 600mm. The rainy season over Korea continues for a month from late June until late July. This rain occurs over a period of 30-40 days. A short period of rainfall comes in early September when the monsoon front retreats back from the north. Two or three typhoons approach the Korean Peninsula from June through September (Embassy of Korea in the U.S.A. 2003).

Hydrological characteristics of rivers vary relating to the climatic condition of region. In the northern part of Japan belonging to cool temperate or subarctic climate regions, the river water level is high in spring due to snow melting, and low and stable in following season. While in the southern part with warm temperate climate, there is no snow-melting flood and the water level irregularly becomes high during rainy and typhoon seasons (Niiyama 1995).

Situation is similar in Korea. The river water levels vary greatly according to the yearly rainfall pattern. Only in summer season usually having abundant rainfalls, the water levels are relatively high, while in the rest of year they are usually low. Only in the eastern and northern mountainous parts of the Korean Peninsula where snow melting affects the stream flow significantly, they are relatively high in spring.

The difference in annual patterns of water-level fluctuation leads to the difference in flora and fauna among rivers. For example, species richness and abundance of willow species increase from southern to northern rivers. That is not only corresponded with thermal regimes but also with the timing of seed dispersal and occurrence of flood which forms open bare land to be colonized by willows (Ishikawa 1983).

3. HISTORY OF RIVER TRAINING PRACTICE IN JAPAN AND KOREA

Modern or western techniques for river improvement were brought to Japan during the later half of 19th century by Dutch engineers. They provided guidance for the carrying out of channel dredging and sand control works to improve navigation. In 1893 and 1896, Japan was ravaged by heavy floods which became the motivation for enacting the River Law. Drafted in 1896, the River Law was to become the mainstay in modern Japan for administration and improvement of rivers to alleviate flood disasters (River Bureau 2003a). In the following period, a series of single-purpose channel works for flood control were progressed.

The second step for river improvement of Japan was achieved by revision of the River Law in 1964. Preceded the revision of the law, necessity of stable water supply had been increased as one of the acts to reconstruct the land after World War II, and hence the Multiple Purpose Development of the Land Act was, the Water for Industrial Use Act and the Waterworks Law were established in 1950, 1955 and 1957, respectively. From the view point of natural disaster, the Ise-wan Typhoon in 1960 took 5000 lives. Soon after the disaster the Erosion and Flood Control Emergency Measures Law was drafted in 1960. Following to these movements, the River Law was finally drafted (River Bureau 2003a). In the revised law, stable water supply was included in the purpose in addition to the flood control, and channelization including dam construction was activated without paying attention to environmental/ecological decline.

Rapid industrialization and urbanization had been occurred in the 1950s and 1960s. In the period, serious problems of water pollution had been tangible. Biological concentration of chemical products was found in 1959 through the effort to clarify the occurring process of Minamata disease, it was caused by taking organic mercury concentrated in fishes through the food web, and the organic mercury was originally contained in the sewage from the factory. Aggravation of water quality and occurrence of the disease led to first movement of river restoration, in terms of improvement of water quality, the third step of river improvement. A system to improve water quality was established in 1969 for urban rivers and in 1974 for extending to all streams. Since then the water quality has been monitored and improved by regulating the discharge of chemicals from factories.

The forth step of river improvement in Japan came through social recognition on the crisis of biodiversity and ecosystems, according to the Red List of Japan, 23.5% (47/200) of mammals, 12.9% (90/700) of birds, 18.6% of amphibians, 21.9% (14/64) of reptiles, 25.3% (76/300) of brackish and fresh water fishes, and 19.8% (1399/7087) of vascular plants have been listed as endangered species (Biodiversity Center of Japan 2003). Due to the increase of social demand for taking back “healthy ecosystems”, a government started to promote the Nature-Oriented River Works in 1990. Parallel to the movement, the Convention on Biological Diversity was signed at the United Nations Conference on Environment and Development, so-called Rio Summit, held in 1992, and biological diversity has been accepted as one of the most important environmental issues in Japan. Hence the National Strategy of Japan on Biological Diversity was drafted in 1995 (revised in 2003). It supported the progression of Nature-Oriented River Works strongly, and consequently the River

Law was revised in 1997 to include conservation and restoration of river environment/ecosystems in its purpose.

In this period, studies for restoring degraded ecosystems in each field of ecology and civil engineering became to be connected, and ecological engineering as inter-disciplinary studies was emergent (Kamada 2001). Academic society of "Ecology and Civil Engineering Society" was founded in 1997 with purposes for achieving co-existence of human and wildlife, biodiversity conservation and maintaining healthy ecosystems.

The trend in South Korea is close to Japan, but rapid progress in urbanization and industrialization was made within relatively short period (Woo *et al*. 2003). People could not recognize fully the seriousness of environmental problems probably until they had experienced twice serious water pollution in the Nakdong River, the phenol pollution incidence in 1991 and the incidence of excess concentration of ammonia nitrogen in the river water in 1994 (Woo and Kim 1995). Those were probably the first national issues of the environmental problems caused by urbanization and industrialization.

Before 1960s, most streams and rivers in Korea were in natural conditions with few artificial structures such as dams and levees. Since the early 1960s, however, the river environment of many streams and rivers has been continuously deteriorated through channelization and water pollution. At present, about 90% of the total reaches of major streams (National Rivers and Class 1 Regional Rivers, total length of 4,100km) in Korea have been channelized. And, about 60% of the Class 2 Regional Rivers (total length of about 26,000km) have been channelized.

In the early 1990s, the necessity of restoring the channelized streams was initiated especially for the urban streams by the social mood of economic achievement and environmental concern. The streams were converted into riverine parks for citizens with an emphasis on aesthetic value.

Stream restoration, restoring the natural function of stream, ecological habitat, started in Korea only in the late 1990s along with a long-term government-supported research, named "Development of close-to-nature river improvement techniques". The Rio Summit in 1992 had the most profound impact on the ecological consideration in the large-scale development projects as well as river planning in South Korea. Basic knowledge and experience of ecological engineering, mostly obtained in Germany, U.S.A. and Japan, have been applied in the river training practices.

4. PRESENT SITUATION OF RIVER ECOSYSTEMS IN JAPAN AND KOREA

Japanese and Korean rivers are under the impacts of dams, sabo works for sediment control, barrages and small weir for irrigation, all of which cause fragmentation of riverine habitats. In the upper reaches, a lot of sabo works for disaster prevention and forest protection have been constructed during the intervening sixty years: *e.g.*, as many as 41 sabo dams exist only in 8 km of the reaches in the Kurama Stream, in Kyoto City (Takemon 1997). Since most of such dams have no fishways, they made serious impacts on stream fishes. Nakano *et al.*

(1996) showed that the fragmentation of the habitats for charr fishes would be capable to result in extinction of their population under conditions of climatic warming in the streams in Hokkaido island. Sabo dams and weirs decrease gradient of stream bed, and thereby create depositional habitat such as sand bars (Takemon 2000a), which have never appeared in original geomorphology in step-pool mountain streams. Takemon (1997) indicates that the upper limit of the distribution of the mayfly *Ephemera strigata* can be shifted with the sabo dam construction through such geomorphological changes. Sediment control in upper reaches of streams results in drastic changes in river ecosystems also in lower reaches.

Rapid increase of vegetation cover on bars has been widely observed in many rivers in Japan. For instance in the Yoshino and Naka Rivers, which are in eastern part of Shikoku Island of Japan and their watershed areas are 3,750 km^2 and 874 km^2, woodland area on bars have largely expanded after 1975 (Fig. 2, Kamada *et al.* 1997, Araki *et al.* 2001). The expansion of vegetation cover in Japanese rivers is considered to be occurred through several and complex ways (Fig. 3).

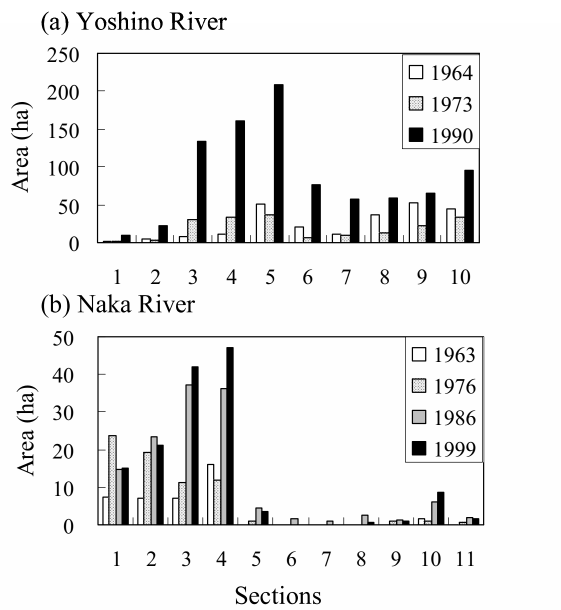


Figure 2. Change of tree-occurring area in (a) the Yoshino River (adapted from Kamada et al. 1997) and (b) the Naka River (Adapted from Araki et al. 2002), Shikoku, Japan.

Dams constructed at upper reaches and gravel mining that was heavily done at lower reach are two main factors to have altered river ecosystems in Japan, as well as river works of straightening channels and embankment. Regulation of flood flow by dams, which have been widely and rapidly constructed from 1950s and started to

cut peak discharge during floods, has reduced flood disturbance and its frequency (Nakamura 1999), and hence increased the chances for trees to survive and grow downstream from the dams, as reported by Johnson *et al*. (1976) and Johnson (1996). The effect of discharge control seems to be considerable in cool temperate zone comparing with warm temperate zone, preceded the summer season that large amount of water is consumed, flowing water is stored in dam to secure stable water supply, and the rate of cutting discharge is larger in cool temperate zone with snow-melt flood than in warm temperate zone without snow-melt flood. The expansion of vegetation cover on bars has been also observed in South Korean rivers such as the Hwang River, and it has been considered to be a result of flow regulation by Hwangang Dam that was newly constructed in 1988 (Woo *et al*. 2003).

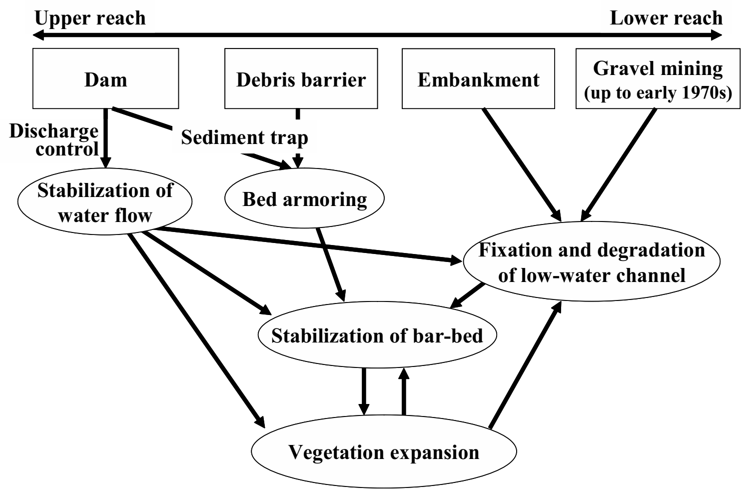


Figure 3. Complex factors affecting the expansion of vegetation cover in Japanese rivers (Adapted from Kamada et al. 1997).

The second factor affecting vegetation expansion is impediment of sediment transportation by dams. For example in the Yoshino River, Naka River and Katsuura River (watershed area is 224 km^2), the total amount of 14 x 10^6, 20 x 10^6, and 15 x 10^5 m^3 of sediment has been trapped by several dams, respectively. Bar surfaces downstream from dams has become covered by coarse sediment (Kamada *et al*. 2002). Fine sediment was washed out by floods and is no longer supplied to the bars because dams trapped the sediment material. Only coarse materials remained on the bar surfaces, which is so called "bed armoring" in river sedimentation engineering (Fig. 4a). Since the armoured bed becomes to be difficult to dislodge during floods, the bar-bed has been more stabilized than before. This means that stable habitats for plants have been formed and are advantageous for successful growth and expansion, such as for *Salix chaenomeloides*, *Alnus serrulatoides*, *Spiraea nipponica* var.

tosaensis and *Elaeagnus umbellata* observed in some rivers of Shikoku (Fig. 4b, Araki *et al*. 2001, Kamada *et al*. 2002, Kohri *et al*. 2000, 2002). Bed armoring due to damming in the alluvial channel in Korea is well documented by Woo *et al* (1994).

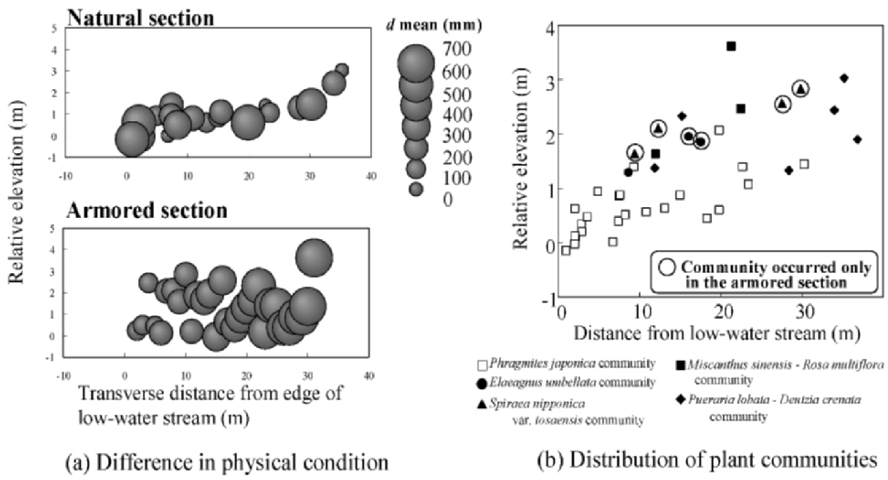


Figure 4. (a) In the Katsuura River, considerable riverbed degradation has been occurred in a reach extending about 8 km downstream from the dam, and obvious armoring of bar areas with coarse gravels resulted. In the natural section, sediment size tends to be small with increase of distance and elevation from low-water stream, but in the armored section, it remains in large even at the high elevation site. (b) Occurring pattern of plant communities were compared between the natural and armored sections. Among five types of plant community, Elaeagnus umbellate community and Spiraea nipponica var. tosaensis community are occurred within the armored section alone. Because the dominant species in the communities prefer areas at relatively high elevations from low-water level and covered with coarse gravels, which condition is only satisfied in armored section. Adapted from Kamada et al. 2002.

In lower reaches of the rivers, large-scale gravel mining was heavily done to obtain constructing materials during the rapid economic growth period of Japan, the 1960s in particular. In the period, serious degradation of river-bed occurred due to removing gravel from the river, and the government became to regulate gravel mining in the early 1970s. In Korea, situation is quite similar to Japan, but with less regulating on gravel mining. Gravel mining destroyed habitats and inhibited establishment of vegetation. Hence when plants become free from disturbance after cessation of gravel mining, they become to be able to grow and expand their area successfully (Kamada *et al*. 1997).

Gravel mining has caused heterogeneous degradation of the river-bed, as well as fixation and convergence of the watercourse due to embankment, the degradation has occurred only in lower reaches of the streams (Takebayashi *et al*. 2003), and the bar-bed elevation from water surface of low-water course has raised comparing with the previous river morphology. Under these circumstances, the intensity of flood disturbance on bar-bed becomes low even during a large flood (Fig. 5). It suggests that vegetation on bars becomes free from flood disturbance and becomes to be able to grow and expand successfully.

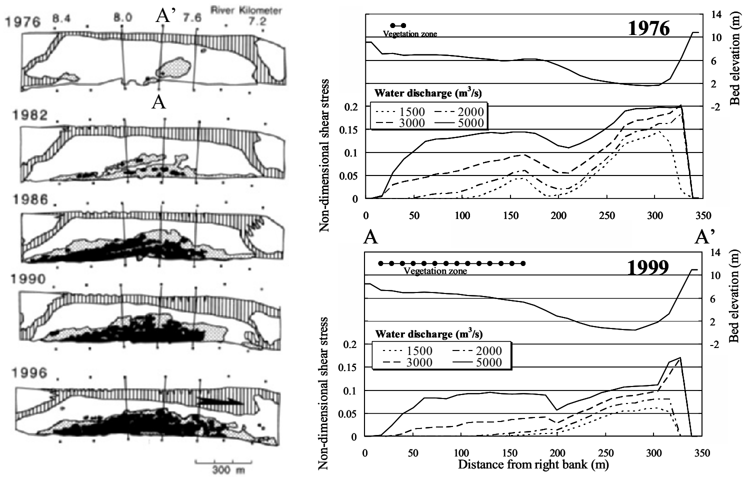
Stabilization of bar-bed is caused not only due to the physical change of river environment but also due to the vegetation newly established on the bar, the vegetation has enhanced the stabilization of the bar (Kamada and Okabe 1998). Continuous aggrading of bar-bed, ranging from 1 to 3 m, has been observed at the bar in the lower reach of the Yoshino River after *Salix chaenomeloides* community was newly established. This is the result of effective trapping of sediment by willow trees. This occurs by slowing water flow and trapping of sediment particles around the roots and stems (Odum 1990). Trapped sediment tends to form itself into a long mound resembling an embankment. Willow trees and the mound significantly restrict the stream width in the event of small or medium-sized floods, and the stream-bed has been continuously scoured. Thus stability of bar-bed seems to have been increased through the effect of vegetation to hydro-geomorphological process, and it has enhanced plants to expand their distribution.

Stabilization of river-bed in downstream reaches from the dam has affected not only on plant communities but also on benthic animals, although the accumulation of scientific knowledge is still little in Japan (Tanida and Takemon 1999, Tsujimoto and Tashiro 2003). The distribution area and population density of an aquatic insect, *Macrostemum radiatum*, have increased after dam construction in the Yoshino River (Furuya, 1998), and it is considered as a result of stabilization of river-bed and increase of productivity of planktons, in terms of food resource for *M. rediatum*, in dam reservoir.

Outbreaks of filamentous green algae have been observed, *Cladophora glomerata* as well as the increase of *M. rediatum* in the Yahagi River (Uchida 1997, 1998, 1999), and *Spirogyra* sp. in the Miya River (Mitsuhashi and Nozaki 1999). It is considered that the outbreaks have been caused by habitat stabilization due to formation of armored river-bed (Uchida 1997) and decrease of discharge by dam operation (Mitsuhashi and Nozaki 1999). The filamentous green algae have poor availability as food for benthic animals and fishes, and damage to *Plecoglossus altivelis* population, which is one of the most important fish for freshwater fishery.

Effects of river-discontinuity due to barrage construction have been well documented in the Nagara River in central Japan, based on five-year monitoring after damming of the barrage in 1995 by the Japanese Ministry of Construction (Tamai 2002, Sasaki *et al*. 2002, Sumitani *et al*. 2002).

Impacts of a barrage on river and estuary ecosystems should vary with its location in the estuarine ecotone. When it situates at lower part of the ecotone, the impacts will be the most serious because of reduction in the tidal dynamics of estuarine water.



(a) Expansion of the vegetation (b) Change of non-dimensional shear stress

Fig. 5. (a) Rapid expansion of vegetation area has been observed on the bar, which locates at around 8 km from the river mouth of the Naka River, Shikoku, Japan. Black area is dominated by shrub species, namely Elaeagnus umbellate*, and dotted area is covered by herbaceous plants (Adapted from Kohri et al. 2002). (b) Along the transverse-line (A-A'), non-dimensional shear stress under several discharges was compared between 1976 and 1999. Low-water channel has been deepened in 1999 comparing to that of 1976, and thus the value of non-dimensional shear stress has become under 0.05 at almost barbed area, even in during the 3000m^3/sec flood that occur in ca. 2-year interval. The value of 0.05 is the upper-limit of that the sediment of bar surface is not dislodged during a flood. The result suggests that the bar becomes to be stabilized and thus becomes appropriate to successful development of plant communities (Kamada and Takebayashi, unpublished).*

This is the case of the Nagara River-mouth Barrage constructed at 5.4 km from the mouth, where the original estuarine ecotone extended over 16 km in length before the construction. In spite of good achievement of fish ways built in the barrage, particularly of the brook-type fish-way, some negative impacts have been reported on migration density of the mitten crab (Takemon 2000b) and Ayu fish (Niimura 2000). Population density and distribution of bivalves were seriously affected by the damming of the barrage not only in the upper reaches but also the

lower reaches of the barrage (Yamauchi 2002), through reduction of DO concentration in the bottom layer in the lower reaches which was caused by the changes in the mixing regime of spring tide from “well mixed” to “partially mixed” conditions (Nakamura and Fujino 2002). Murakami (2002) reported on potamoplankton and its blooms occurred in the upper reaches of the barrage after damming of the barrage. These facts show that damming of the river-mouth barrage caused degeneration and discontinuity of biological communities. Although the fishways of the barrage have functioned as a mitigation facility for selected animals, they are not enough for restoration of the estuary ecotones.

5. FUTURE PROSPECT OF RIVER RESTORATION IN JAPAN AND KOREA

In Japan and Korea, many stream reaches are in the stages of “disaster-prevention stream” and “occupied stream” with few remaining in the stage of “natural stream”. Disaster-prevention stream denotes the channelized stream for water control, especially during flood, characterized with the altered channel and man-made embankment for increasing the stability of river conditions. This kind of stream has a high ‘social value’ of water control or flood control. Occupied stream is the stream part of which is occupied or reclaimed for the purposes other than those belonging authentically to the stream, such as farmland and athletic field in the suburban streams and parking lots and roads in the urban streams (Woo 2003). The effort for stabilizing the river condition has resulted in considerable alteration of river ecosystems in Japan and Korea, as mentioned in the previous chapter.

The ultimate goal of the restoration of river ecosystem, therefore, is to take back dynamic process of the river system, allowing rivers to form their shape by themselves through free water-flow, free sediment-transportation and free meander, etc. An experimental project has been carried out at the Yahagi River in central Japan, initiated by the Fishery Cooperative Society of the Yahagi River, in order to prevent outbreaks of filamentous green algae, gravels were thrown into river-bed to increase river-bed mobility (Uchida 2000, Tsujimoto and Tashiro 2003). Similar attempt have been conducted at a downstream reach of the Miharu Dam, northern part of Japan (Azami *et al*. 2003). Pilot projects to restore the original meandering channel and floodplains have been started in Kushiro Mire and the Shibetsu River, Hokkaido, Japan (Nakamura 2003). In the project, an ideal way for adaptive management will be conducted, by which expected are increase in the scientific and practical knowledge for prediction and monitoring of ecosystem change. Extremely high land price, however, might become strong limitation to progress the re-meandering works in both countries, because it is necessary to obtain land wide enough for the works. The pilot project for river restoration is also ongoing in South Korea (Woo 2003). The goal of the project is to restore the physical habitat of the stream harmonized well with stream scenery and to maintain and assure flood conveyance. Assuring the flood control capacity appears to be non-negotiable in the stream restoration works in Korea. With this goal, the pilot project has following three design principles, namely restoring the dynamics and continuity of stream flow and non-uniformity of stream morphology and material.

In order to progress the re-meandering works all over the country, the concept of 'a society living with flood' should be accepted in the society because almost all of the floodplain area has been intensively inhabited both in Japan and South Korea. This concept is based on the fact that man can not completely defend himself from flood. At least, man should know that sometimes it is less efficient and effective to try to make a complete flood defence in every river. On the contrary, we had better think to be able to render flood to take the riverine lands, which were mostly parts of the floodplains. In some extent, policy for flood management of Japanese authorities is changing from that confining the flood within a river to that allowing the flood to overflow into part of farmlands where is functioned as the retarding water ground.

Dam decommissioning is another part of river restoration. It has been already begun both in Europe and USA. At present, they only consider small and outdated dams and weirs the functions of which are already been finished (Doyle *et al*. 2003). There are numerous dams and weirs in Japan and Korea. Some of them, especially small weirs that had been constructed originally for channel irrigation, have lost their original function because neighbouring paddy lands were already converted into urban areas and other uses. Among those small dams or weirs with their functions lost or finished, we can first consider dam removal for restoring channel corridor continuity. In this case, ecological engineers must concern the physical, chemical and ecological impacts of the dam removal and best practice management of the river reach after dam removal (Stanley and Doyle 2003).

For progressing restoration works in Japan and South Korea, where the ecological engineering for riparian restoration is still beginning stage, several issues are strongly recommended. First, we have to progress the further interdisciplinary approaches (Kamada 2001). Geomorphology and hydrology are combined with geography and ecology in addressing riparian restoration approaches (Landers 1997). Cooperation with economist and sociologist is also necessary. Landscape ecological approach to consider appropriate distribution of land uses in a watershed is a scope of ecological engineering for river restoration.

Second, river restoration should be designed within a hierarchy of scale. The concept of the expected temporal variations associated with a particular riparian spatial unit over various time scales is important in all aspects of restoration (Landers 1997). Researches have to be done at multiple scales of time and space. GIS is the essential tool for capturing phenomena within the hierarchy of scales.

Third, methods to identify riparian sites most suitable for restoration and preservation should be developed (O'Neill *et al*. 1977), as well as getting the concrete image and techniques for the restoration. Baseline data that is linkable with the GIS must be arranged beyond the authorizing bodies and open to the public (Nakamura 2003). Endpoint and reference condition should be defined. An endpoint is some aspect of the selected system that can be measured and quantified and that is expected to change as system function trends toward improvement or degradation. Reference condition is a vital component of any restoration activity, in that only through establishing some version of reference conditions can restoration goals be determined (Landers 1997).

Finally, the adaptive management approach under public involvement is the essential for progressing restoration works (Christensen *et al*. 1996, Kamada 2001),

although the concept is still unfamiliar in the society of Japan and Korea. In order to achieve the adaptive management, the necessary is to develop hypotheses from observations, to establish available information and modelling, to select indicators, and to set goals. To accomplish adaptive management, an appropriate monitoring regime is required so that information can be gained to evaluate progress and to test hypotheses, applying the Before-After-Control-Impact design, the Before-After-Reference-Impact (BARI) design, and the most powerfully the Before-After-Reference-Control-Impact (BARCI) design (Stewart-Oaten *et al*. 1986, 1992, Lake 2001). The monitoring should be conducted under the cooperation with NPOs, the local residents and managing authorities. Researchers have to take continuous efforts to return the scientific and practical knowledge to the public.

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7. REFERENCES

Araki, K., Tono, T., Kamada, M., Yuki, T. and Okabe, T. 2001. Temporal change of woody plant distribution on bars in relation to the change of physical condition of bar-beds in middle and lower reaches of the Naka River, Shikoku, Japan. *Proceedings of 28th Annual Meeting of Environmental Systems Research 2001* (pp. 51-56).

Azami, K., Urakami, M. and Ito, H. 2003. River bed restoration by sediment input and flushing discharge in the downstream of the Miharu Dam. *Proceedings of the First Japan-South Korea Joint Seminar on Ecology and Civil Engineering* (pp. 85-92).

Bravard, J.P., Amoros, C. and Pautou, G. 1986. Impact of civil engineering works on the succession of communities in a fluvial system. *Oikos* 47: 92-111.

Biodiversity Center of Japan. 2003. Threatened species. Retrieved from the Web 10/4/2003. http://www.biodic.go.jp/english/rdb/rdb_f.html

Brookes, A. 1988. *Channelized Rivers, Perspectives for Environmental Management*. Wiley, Chichester.

Décamps, H., Fortuné, M., Gazelle, F. and Pautou, G. 1988. Historical influence of man on the riparian dynamics of a fluvial landscape. *Landscape Ecology* 1: 163-173.

Doyle, M.W., Harbor, J.M. and Stanley, E.H. 2003. Toward policies and decision-making for dam removal. *Environmental Management* 31: 453-465.

Embassy of Japan 2003. Basic / general information on Japan. Retrieved from the Web 8/4/2003. http://www.us.emb-japan.go.jp/faq/basic.htm

Embassy of Korea in the U.S.A. 2003. Visiting Korea. Retrieved from the Web 8/4/2003. http://www.koreaembassy.org/visiting/index.cfm

Furuya, Y. 1998. Downstream distribution and annual changes in densities of net-spinning *Trichoptera* (Hydropsychidaeand Stenopsychidae) in the Yoshino River, Shikoku, Japan, with special reference to the colonization of *Macrostemum radiatum* MCLACHLAN (Trichoptera: Hydropsycheidae). *The Japanese Journal of Limnology* 59: 429-441.

Goodwin, C.N., Hawkins, C.P. and Kershner, J.L. 1997. Riparian restoration in the western United States: overview and perspective. *Restoration Ecology* 5 (4S): 4-14.

Christensen N.L., Bartuska, A.M., Brown J.H., Carpenter S., D'Antonio C., Francis R., Franklin J.F., MacMahon J.A., Noss R.F., Parsons D.J., Perterson C.H., Turner M.G. and Woodmansee R.G. 1996. The report of the ecological society of America committee on the scientific basis for ecosystem management. *Ecological Applications* 6: 665-691.

Harper, D.M. and Ferguson, J.D. 1995. *The Ecological Basis for River Management*. Wiley, Chichester.

Ishikawa, S. 1983. Ecological studies on the floodplain vegetation in the Tohoku and Hokkaido districts, Japan. *Ecological Review* 20: 73-114.

Ishikawa, S. 1991. Floodplain vegetation of the Ibi River in central Japan II. Vegetation dynamics on the bars in the river course of the alluvial fan. *Japanese Journal of Ecology* 41: 31-43.

Jansson R., Nilsson, C., Dynesius, M. and Andersson, E. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. *Ecological Applications* 10: 203-224.

Johnson, W.C. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. *Ecological Monographs* 64: 45-84.

Johnson, W.C., Burgess, R.L. and Keammerer 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. *Ecological Monographs* 46: 59-84.

Kamada, M. 2001. Importance of inter-disciplinary studies between ecology and hydraulic engineering. *Japanese Journal of Ecology* 51: 261-267.

Kamada, M. and Okabe, T. 1998. Vegetation mapping with the aid of low-altitude aerial photography. *Applied Vegetation Science* 1: 211-218.

Kamada, M., Okabe, T. and Kotera, I. 1997. Influencing factors on distributional change in trees and land-use types in the Yoshino River, Shikoku, Japan. *Environmental systems research* 25: 287-294.

Kamada, M., Kojima, M., Yoshida, R., Asai, K. and Okabe, T. 2002. Influence of dam construction on distribution of riparian plant communities in the Katsuura River, Shikoku, Japan. *Ecology and Civil Engineering* 5: 103-114.

Kohri, M., Kamada, M., Okabe, T. and Nakagoshi, N. 2000. Distribution pattern of *Elaeagnus umbellata* communities on the gravel bars in relation to hydrogeomorphic factors in the Yoshino River, Shikoku, Japan. *Environmental Systems Research* 28: 353-358.

Kohori, M., Kamada M., Yuuki T., Okabe T. and Nakagoshi N. 2002. Expansion of *Elaeagnus umbellata* on a gravel bar in the Naka River, Shikoku, Japan. *Plant Species Biology* 17: 25-36.

Kuramoto, N. 1995. Conservation biological studies on *Aster kantoensis* along the Tama River. *Bulletin of the Laboratory of Landscape Architecture and Science, the University of Tokyo* 15: 1-120.

Kuramoto, N. 1997. Studies and practices of conservation of *Aster kantoensis*. *Japanese Journal of Conservation Ecology* 2: 43-53.

Lake, P.S. 2001. On the maturing of restoration: linking ecological research and restoration. *Ecological Management and Restoration* 2: 110-115.

Landers, D.H. 1997. Riparian restoration: current status and the reach to the future. *Restoration Ecology* 5 (4S): 113-121.

Matsumoto, J., Muraoka, H. and Washitani, I. 2000. Whole plant carbon gain of an endangered herbaceous species *Aster kntoensis* and the influence of shading by an alien grass *Eragrostis curvula* in its gravy floodplain habitat. *Annals of Botany* 86: 787-797.

Mitsuhashi, H. and Nozaki, K. 1999. Bloom of filamentous green algae Spirogyra sp. in Miya-gawa River, Mie Prefecture. *Biology of Inland Water* 14: 9-15.

Mori, S. 1999. Dam and fish life history, ecological perspectives in the environmental conservation. *Ecology and Civil Engineering* 2: 165-177.

Murakami, T. 2002. Development of planktonic algae and its environmental impacts subsequent to construction of the Nagara Rivermouth Barrage. *Ecology and Civil Engineering* 5: 41-51.

Muranaka, T. and Washitani, I. 2001. Alien plant invasions and gravelly floodplain vegetation of the Kinu River. *Ecology and Civil Engineering* 4: 121-132.

Nagasaka, A. and Nakamura, F. 1999. The influences of land-use changes on hydrology and riparian environment in a northern Japanese landscape. *Landscape Ecology* 14: 543-556.

Nakamura, F. 1999. Influence of dam structure on dynamics of riparian forests. *Ecology and Civil Engineering* 2: 125-139.

Nakamura, F. 2003. Restoration strategies for rivers, floodplains and wetlands in Kushiro Mire and Shibetsu River, northern Japan. *Ecology and Civil Engineering* 5: 217-232.

Nakamura F., Sudo, T., Kameyama, S. and Jitsu, M. 1997. Influence of channelization on discharge of suspended sediment and wetland vegetation in Kushiro Marsh, northern Japan. *Geomorphology* 18: 279-289.

Nakamura, Y. and Fujino, T. 2002. Dynamics of dissolved oxygen concentration in the lower reaches of rivermouth barrage of the Nagara River. *Ecology and Civil Engineering* 5: 73-84.

Nakano, S. Kitano, F. and Maekawa, K. 1996. Potential fragmentation and loss of thermal habitats for two charr species in the Japanese archipelago due to climatic warming. *Freshwater Biology* 36: 711-722.

Niimura, Y. 2000. The guide-flow fishways and the brook-type fishways at the Nagara River mouth Barrage: comparison of function during migration of Ayu fry. *Ecology and Civil Engineering* 3: 169-178.

Niiyama, K. 1995. Life history traits of salicaceous species and riparian environment. *Japanese Journal of Ecology* 45: 301-306.

Odum, W.E. 1990. Internal processes influencing the maintenance of ecotones: do they exist? In R.J. Naiman and H. Décamps (Eds.), *The Ecology and Management of Aquatic-Terrestrial Ecotones* (pp. 91-102). Unesco-Parthenon Publishing, Paris.

O'Neill, M.P.J., Schmidt, J.C., Dobrowolski, J.P., Hawkins, C.P. and Neale, C.M.U. 1997. Identifying sites for riparian wetland restoration: application of a model to the Upper Arkansas River Basin. *Restoration Ecology* 5 (4S): 85-102.

Primack, R. B. 1995. *A Primer of Conservation Biology*. Sinauer Association Inc.

River Bureau [Ministry of Land, Infrastructure and Transport, Japan]. 2003a. Land and climate of Japan. Retrieved from the Web 9/4/2003. http://www.mlit.go.jp/river/english/land.html

River Bureau [Ministry of Land, Infrastructure and Transport, Japan]. 2003b. Retrieved from the Web 8/5/2003. http://www.mlit.go.jp/river/jiten/toukei/index.html

Sasaki, K., Murakami, Y., Sasaki, K. and Takagi, M. 2002. A review of monitoring in a post-construction stage of the Nagaragawa estuary barrage from administrative point of view. *Ecology and Civil Engineering* 5: 5-22.

Stanley, E.H. and Doyle, M.W. 2003. Trading off: the ecological effects of dam removal. *Frontiers in Ecology and the Environment* 1: 15-22.

Stewart-Oaten, A., Mudoch, W.W. and Parker, K.R. 1986. Environmental impact assessment: "pseudoreplication" in time? *Ecology* 67: 929-940.

Stewart-Oaten, A., Bence, J.R. and Osenberg, C.W. 1992. Assessing effects of unreplicated perturbations: no simple solutions. *Ecology* 73: 1396-1404.

Sumitani, M., Nagase O. and Kinoshita, M. 2002. Studies on the fishways and migratory fish species of the Nagaragawa Estuary Barrage. *Ecology and Civil Engineering* 5: 23-40.

Takebayashi, H., Egashira, S. and Okabe, T. 2003. Numerical analysis of braided streams formed on beds with non-uniform sediment. *Annual Journal of Hydraulic Engineering, JSCE* 47: 631-636.

Takemon, Y. 1997. Management of biodiversity in aquatic ecosystems: dynamic aspects of habitat complexity in stream ecosystems. In T. Abe, S.A. Levin and M. Higashi (Eds.), *Biodiversity: An Ecological Perspective* (pp. 259-275). Springer, New York.

Takemon, Y. 2000a. Reproductive behaviour and morphology of *Paraleptophlebia spinosa* (Ephemeroptera: Leptophlebiidae): implications of variation in copula duration. *Limnology* 1: 47-56.

Takemon, Y. 2000b. Evaluation of fishways of the Nagara Rivermouth Barrage based on upstream migration of the Japanese mitten crab, *Eriocheir japonica* (de Haan). *Ecology and Civil Engineering* 3: 153-168.

Tamai, N. 2002. Evaluation of the five-year monitoring in the operation stage of the Nagaragawa estuary barrage. *Ecology and Civil Engineering* 5: 1-3.

Tanida K. and Takemon, Y. 1999. Effects of dams on benthic animals in streams and rivers. *Ecology and Civil Engineering* 2: 153-164.

Tsujimoto, T. and Tashiro, T. 2003. Ecosystem degradation and possible restoration –case study in the middle reach of the Yahagi River. *Proceedings of the First Japan-South Korea Joint Seminar on Ecology and Civil Engineering* (pp.95-100).

Uchida, A. 1997. Attached algae and benthic invertebrates of the Yahagi River. *Report of Yahagi River Institute* 1: 59-80.

Uchida, A. 1998. Attached algae and benthic invertebrates of the Yahagi River, Part 2. *Report of Yahagi River Institute* 2: 19-31.

Uchida, A. 1999. Attached algae and benthic invertebrates of the Yahagi River, Part 3. *Report of Yahagi River Institute* 3: 19-33.

Uchida, A. 2000. Attached algae and benthic invertebrates of the Yahagi River, Part 4. *Report of Yahagi River Institute* 4: 5-17.

Vannote R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-137.

Woo, H.S. and Kim, Y. 1995. An analysis of the effect of water release from upstream reservoirs on diluting and flushing pollutants in downstream river reach. *Proceedings of 26th IAHR* 4: 350-355.

Woo, H.S. and Lee, J. 1993. An analysis of flow characteristics of major rivers in Korea. *Proceedings of the 1st International Conference on Hydroscience and Engineering (Washington D.C., USA),* 1(B): 1271-1276.
Woo, H.S. and Yu, K. 1994. Prediction of River Profile Changes Downstream of the Daecheong Dam by Using the Computer Program HEC-6. *Proceedings of the 18th Congress of ICOLD* 2: 99-110.
Woo, H.S. and Yoon, B. 2002. Sediment problems and research in Korea. Proceedings of the 4th International Conference on Hydroscience and Engineering (Warsaw, Poland), Track SE5. *(in CD)*
Woo H.S., Kim, H.S. and Ahn, H.K. 2003. Situation and prospect of ecological engineering in Korea. *Ecology and Civil Engineering* 6: in press.
Yamauchi, K. 2002. Effects of Nagara Rivermouth Barrage on the river-bed sediment and bivalves in the lower reaches of the Nagara River. *Ecology and Civil Engineering* 5: 53-71.
Yim, Y.J. and Kira, T. 1975. Distribution of forest vegetation and climate in the Korean Peninsula, I. Distribution of some indices of thermal climate. *Japanese Journal of Ecology* 25: 77-88.
Yim, Y.J. and Kira, T. 1976. Distribution of forest vegetation and climate in the Korean Peninsula, II. Distribution of climatic humidity/aridity. *Japanese Journal of Ecology* 26: 157-164.
Yim, Y.J. and Kim, S.D. 1983. Climate-diagram map of Korea. *Korean Journal of Ecology* 6: 261-272.

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YEONG-KOOK CHOI

CHAPTER 22

BAEKDUDAEGAN, THE CENTRAL AXIS OF THE KOREAN PENINSULAR - THE PATH TOWARD MANAGEMENT STRATEGIES REGARDING TO ITS CONCEPTS

1. INTRODUCTION

It is not known well when the concept of the "Baekdudaegan[i]" was formed and defined. Other similar concepts could be construed as being used in some old literatures, considering the fact that Koreans have traditionally treated territory configuration very important. We can find one evident record (Lim 1999) in Goryeosa[ii], which shows that the terrestrial stratum from Baekdu Mountain was then recognized as a kind of "flowing" of national territory. In the Joseon period, Lee Ik(1681-1763) with a literary name of Seongho and Shin Gyeong-jun(1712-1781) with a literary name of Yeoam suggested more concrete conception of the "Baekdudaegan" in *Baekdujeonggan* and *Sansugo* and *Sangyeongpyo*[iii], respectively. From the fact that many literatures about the Baekdudaegan have been published after the mid of Joseon period, we find out that people have been interested in national territory and tried to formulate a general system of mountain ranges of the Baekdudaegan since the 18th century.

Figure 1. View of Hwanggeum Ridgeline and Cheonwang Peak from Gugok Peak

S.-K. Hong et al. (eds.), Ecological Issues in a Changing World – Status, Response and Strategy 355-384.

The Baekdudaegan means the contiguous line of terrestrial stratum from Baekdu Mountain to Jiri Mountain without crossing valleys or streams (Yang 2002). It is the central axis of the Korean peninsula, which is connected from Baekdu Mountain, as well as the backbone of mountain ranges. The Baekdudaegan is based on Koreans' traditional conception of geography, which highlights connected configuration of mountains as shown on the premise of 'mountain ranges divide streams,' rather than typical geographical conception of a mountain range. In this regard, regional boundaries and characteristics of the districts on the Baekdudaegan are identical with the mountain ridge. The Baekdudaegan has affected dominantly the formation of common and different features of administrative, cultural and living style between regions. It exits in substance in terms of geography and no doubt in spirit of the Korean people as well.

Since the 1990s when the concept of the Baekdudaegan began to be known, it has been recognized that various species of fauna and flora inhabit around the Baekdudaegan, which is definitely special existence to be preserved (Korea Forest Service 1997).

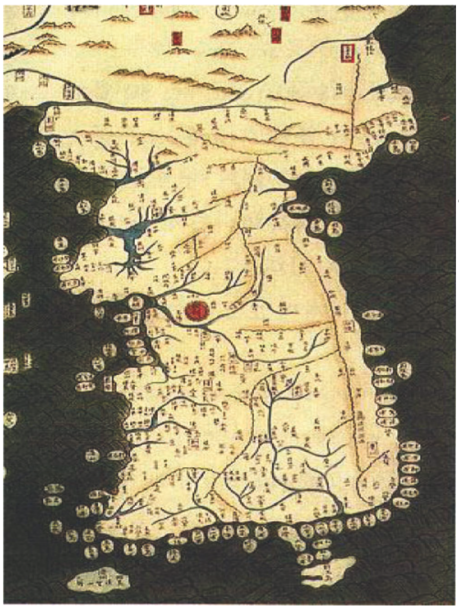

Figure 2. A Part of the Honil Gangri Yeokdae Gukdo Jido remade on the basis of its original map in 1402

Figure 3. Configuration of the Baekdudaegan

It is realized that both the natural environment of the Baekdudaegan has been deteriorated and its original meaning distorted as well due to massive development in the process of economic growth for the last four decades. As a result, social demand that the natural environment and original meaning of the Baekdudaegan should be preserved and managed has been increasing.

In this viewpoint, this paper focuses on the concept of the Baekdudaegan and the establishment of basic polices to preserve and manage the Baekdudaegan. We need to examine the significance of the Baekdudaegan, so as to ensure why and how we should manage it. And in the section of policies to manage the Baekdudaegan, it is suggested what we have to pay due regard to when promoting its management policies, in terms of the necessity to substantialize the Baekdudaegan as conceptual existence into more spatialized significance.

2. SIGNIFICANCE OF THE BAEKDUDAEGAN

Prior to review of its significance, we need to examine the concept of the Baekdudaegan mainly in two viewpoints: firstly, we attempt to analyze its characteristics shown in old pictorial maps to examine its own conceptual significance. Secondly, we try to research its scenic and ecological significance from a modern standpoint, considering the fact that the Baekdudaegan has begun to be well known due to its value as biological resources.

2.1. The concept of the Baekdudaegan

2.1.1 The characteristics of the Baekdudaegan shown in old maps[iv]

As the oldest existing map in Korea, the Honil Gangri Yeokdae Gukdo Jido[v], which is a world map to show Japan, Africa, Europe as well as Korea, depicts the Baekdudaegan in the form of lines (Lee 1991). It shows major rivers and mountains including the Baekdudaegan in Korea. The lines of the Baekdudaegan look very similar with the outline of the Korean peninsula drawn in the old maps in the late Joseon period. In the Honil Yeokdae Gukdo Gangri Jido, which is supposed to have been made in the middle of 16th century, Baekdu Mountain is remarkably depicted although the outline of the Korean peninsula is unclearly drawn. In this regard, we could recognize the Korean ancestors' view and attitudes toward their nature and national territory from the fact that they esteemed Baekdu Mountain and its connected mountain ridges. With the examination of old maps during the Joseon period, the Baekdudaegan was getting presented more plainly and concretely in the maps of the late Joseon period although Baekdu Mountain was depicted as a symbol of Korean spirit in the maps of the early Joseon period.

2.1.2 Foundation of natural structure of the Korean peninsula

From the ancient times, the Korean ancestors understood the terrestrial stratum from mountains as a kind of “flowing” of land as shown in the concept of the Baekdudaegan (Lee 2002). In the old literatures such as Sejongsilok Jiriji (geographical record of King Sejong’s reign, 1454), Baekdujeonggan (part of Seonghosaseol, a kind of encyclopedia by Lee Ik, published around 1740), Sansugo and Sangeongpyo (geographical records by Shin Gyeong-jun), etc., the Baekdudaegan referred to Baekdu Mountain and its connected branches and it was regarded as one system including the Baekdudaegan and its spreading ridges as well in the late Joseon period (Yang 2002). In Baekdujeonggan, describes that the left ridge of the Baekdudaegan runs along the East Sea from the beginning to the end of ocean, showing the fact that it regards the structure of mountain ranges as one system.

The concept of the Baekdudaegan began to be recognized from the Goryeo period and became more concrete since the 18th century when public concerns of national territory were increasing[vi]. A series of a mountain group stretching southward from Baekdu Mountain was substantialized as a central conception in the structure of mountain. That is to say, the Baekdudaegan was recognized geographically as a kind of “flowing” from Baekdu Mountain in the early Joseon period. But, in the late Joseon period it became to have the significance related with the life of Koreans such as social, culture and political aspects of the Korean peninsula. With this kind of concept, the traditional system of mountainous districts was established on the boundaries of living life in accordance with mountains and rivers (Lim 1999). It shows balanced viewpoints toward national territory connecting mountainous districts and boundaries of people’s life.

Figure 4. The Baekdudaegan in South Korea (Hyangro Peak~Cheonwang Peak)

2.1.3 Baekdudaegan in geographical viewpoints

According to *Sangyeongpyo*, all the mountain ranges and ridges in the Korean peninsula are classified into one Daegan, namely the Baekdudae-gan as a geographical center, one Jeonggan, and thirteen Jeongmaek. [vii] Jeonggan, and Jeongmaek form major river watersheds, from which main mountain ranges spread with some

ridges. It means that the Baekdudaegan is a standard for the boundaries of districts, dividing water stream of the peninsula into eastward and westward directions.

The Baekdudaegan consists of about 487 mountains, hills and peaks (Ministry of Environment 2001). Therefore, it is possible to travel from the beginning to the end along the ridgelines without crossing any rivers or streams. In this regard, the ridgelines have significance in the structure of the Baekdudaegan. But no one can say that the ridgelines mean all about the Baekdudaegan. Daegan and Jeongmaek are mountain ridges dividing water stream and have made boundaries of districts, thus affecting the living and cultural styles of people. We can see the example in the case of the Gwandong, Yeongseo, and Honam regions, which are divided by Jeongmaek, showing differences in the residents' living and social style. Since Daegan and Jeongmaek run along the ridgelines, it is difficult for people to access them, thus regarded as well defensible location. Therefore, Daegan has played a role of the boundaries of districts for defense and administration. In this regard, the Baekdudaegan can be recognized as a comprehensive geographical system, which is considered in social and cultural aspects such as history and culture, as well as in natural environmental aspects.

2.1.4 Baekdudaegan in the viewpoints of landscape ecology[viii]

The mountain ridges in Korea can be presented with two terms: 'Daegan' in a traditional way as shown in this paper and 'range' in a modern way. Mountain range comes from a geographical point of view, considering the directions of spreading branches from mountains, and on the other hand, 'Daegan' focuses on the natural features from the perspective of landscape, naturally used to divide watershed (Lee 2002) in the Korean peninsula.

Figure 5. Configuration of the Korean peninsula in a part of Daedongyeojido

Figure 6. Configuration in the map derived from satellite data

The Baekdudaegan is appropriate to analyze the function of ecological corridors because it divides living and cultural spheres and includes some waters with geographical continuousness. These characteristics could be key factors to keep forestry forming the environment surrounding the Baekdudaegan and to acquire sustainable ecological system in Korea.

Accordingly, it is important to research the Baekdudaegan from the landscape ecological perspective, so as to make a direction for policies to manage the Baekdudaegan. The landscape ecological analysis of the Baekdudaegan depends on the spatial extent of the Baekdudaegan. According to the extent, the qualitative and quantitative status of biological resources in the Baekdudaegan would be different, consequently making results of the analysis different. In order to analyze the landscape ecological characteristics of the Baekdudaegan, it is important to examine the functional connection among comprising factors of ecosystem. This examination is conducted by investigating changing status of land surface, resulting from human activities, as well as biological resources distributed around the Baekdudaegan. In particular, we should concentrate on the connection of various spatial components for movement of animals and plants, materials, and information, which is related with the concept of the Baekdudaegan as a corridor or a patch of the Korean peninsula (Lee 2001). For this reason, it is more important than others to continuously investigate biological resources of the Baekdudaegan and their changing status.

The landscape structure and functions of the Baekdudaegan have been ceaselessly changed by their mutual effects. It is concerned that the forest and rivers have been changed by human activities such as industry development and national land use rather than by natural activities such as movement of wild animals. In addition, the ecosystem of the Baekdudaegan is not possible to adapt to these fast changing human activities. And the most concerned thing is that the Baekdudaegan cannot help being influenced by these activities due to its humanities and social characteristics. In other words, it is, so-called, a treasure house and source of natural habitat and on the other hand, its backbone forms a natural boundary between east and west in the Korean peninsula. In this regard, people have tried to overcome this divide with various activities. As a result, it is a burden to consider both of these problems in managing the Baekdudaegan.

2.2 Significance of the Baekdudaegan

2.2.1 Source of History and Culture

Figure 7. Cheonjedan

According to the traditional geographical view centered on the Baekdudaegan, mountains and hills in the Korean peninsula stretch from Baekdu Mountain. This kind of view is attributable to the fact that the prosperity of the nation and people is believed to connect with the extending of mountains from Baekdu Mountain. For example, according to *Goryeosa* and *Goryeo Segye*,[21] the land features of the peninsula are made up of "su(water)" and "mok(trees)," coming from Baekdu Mountain.[21] And it is here described that if someone builds a house by following "su" and "mok," based on the theory of geomancy, he would have an intelligent boy (it means here, "Wanggeon," the first king of the Goryeo Dynasty). These geographical features are linked with the life of the Korean people, due to the fact that they have highly esteemed mountains as a source of their life from the ancient times (Lim 1999).

It is true that the Baekdudaegan has played the role of a root in the spirit of the Korean people because they have admired mountains and land, which have dominantly affected them. If one people has lived in one limited land space for tens of centuries, the culture and history such as the people's living style and way of thinking could be largely influenced by the geographical environment, that is, territory configuration of the land. In particular, Korea has been affected evidently by mountains and hills, of which 67% of national territory is composed.

The Korean people have treated mountains as origin of their history and culture (Shin 2002). The Baekdudaegan is a ground where they are born, brought, and reposed, representing their ancestors' geographical viewpoint that all mountain ranges in the Korean peninsula stretch along rivers and streams. The Baekdudaegan is a basis naturally dividing boundaries of the culture of life such as boundaries of districts, the creation of a city, cuisine, fashion, dialect and standard language, agriculture, commerce, meteorology, etc. It is also an origin of all rivers in the Korean peninsula including the ten largest rivers. In short, the Baekdudaegan is the foundation of the national identity distinctive to Korea, which contains history and living culture including traditional geography.

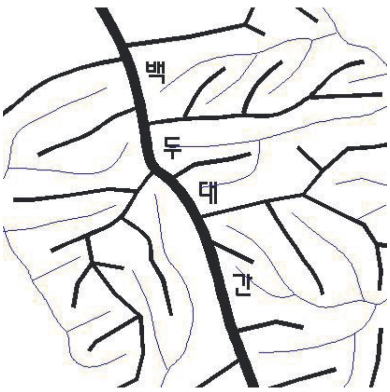

Figure 8. Mountain ridges and streams in Sangyeongpyo

Figure 9. Forest Ecosystem Restoration Area in Mt. Taebaek

2.2.2 The Korean People's Viewpoints toward Nature

Based on the principle of "A mountain ridge ends with water," mountains and rivers are presented separately in old Korean maps. The concept of "Mountains cannot run across rivers, and rivers cannot run over mountains," which shows the Korean people's point of view toward nature, is applied in apprehending the geographical structure of the Baekdudaegan. The features of Jeongmaek as well as the Baekdudaegan are analyzed to reflect the Korean people's outlook on nature to adapt them to a law of nature, considering that various living and cultural styles are formed along with the Baekdudaegan.

The Baekdudaegan represents nature-centered spirituality (Park 2002) of the Korean people who believe that the Baekdudaegan reflects the "flowing" of national territory. The modern system of mountain ranges is established on the basis of geological structures, and on the other hand, the Baekdudaegan is embodied with the features of mountains and rivers, which are the basis of the Korean people's life (Yang 2002). In this regard, the living style of the Korean people also has been formed in harmony with nature.

2.2.3 Treasure house of various biological resources

The Baekdudaegan with large-scale forestry, which has formed in the climatic and geographical operations for the ancient times, has an ecological importance with the advance and retrogression of fauna and flora in the Korean peninsula. Firstly, it is playing a central role in forestation. Secondly, it provides water resources, oxygen, and rest with a function for the public good and produces timber, forest products, minerals, etc. In addition, it is meaningful as a space of living life. Thirdly, the Baekdudaegan, composed of huge mountains, is constructing aquifers of the Korean peninsula with underground layer of porous stone that yields water (Lee 2002). And finally, it contributes to biological diversity by providing the wildlife habitats and corridors along ridgelines.

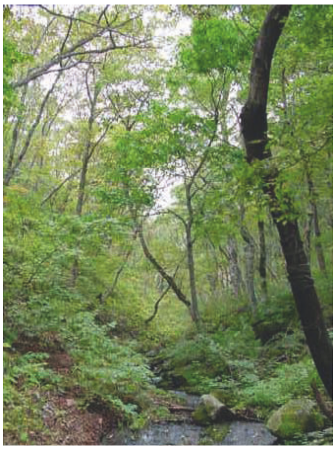

Figure 10. Gojeokdae Valley

In the landscape ecological viewpoints, the Baekdudaegan could be regarded as a corridor (Forman and Liere 1986) or a patch of the Korean peninsula. It means that from the perspective of the whole country the Baekdudaegan with huge forestry is referred to a patch for a mosaic of the Korean peninsula or a massive corridor in terms of its long shape. The Baekdudaegan is reckoned as an ecological axis of national territory, not just because of its geographical connectivity. When watching the flow of energy and the exchange of information

between individual components of ecosystem (Naveh and Lieberman 1993), the connection of the components could be regarded as an ecological axis. In this regard, we need to examine functions and changes of landscape.

In terms of its geographical connectivity, the Baekdudaegan could be treated as an eco-corridor for wild animals. To make the Baekdudaegan as a corridor of movement of materials, energy and information, we need to facilitate the functional connectivity among ecological components. When the Baekdudaegan functions as a corridor of movement of these ecological components, it would be regarded as one of eco-networks.

3. CURRENT SITUATION AND ISSUES FOR MANAGING THE BAEKDUDAEGAN

Prior to establish the management policies, we need to examine current problems of the Baekdudaegan. The tasks ahead for the Baekdudaegan are suggested after examining current conditions of its natural and social environment and how we have managed the Baekdudaegan.

3.1 Current Situation[xi]

3.1.1 Natural environment of the Baekdudaegan

The Baekdudaegan runs from North to South parallel to the East Sea of Korea, dividing it into eastern region and the western region of the Korean peninsula. The mountain ridge in the east forms steep slopes and is affected by oceanic climate, whereas gradual slopes along the west coast are under the influence of a continental climate. The Baekdudaegan is composed of relatively well-grown forests. In terms of horizontal distribution of fauna and flora by latitude, forests of the Baekdudaegan in part of South Korea are included into temperate zones. In the lowland forest zones, forests of pines are there and forests of fallen broad-leaved trees like Mongolian oaks are found out in the alpine zones. In terms of vertical distribution by altitude, most areas of the land have forests of broad-leaved trees, but some part of it has more subalpine forests.

Figure 11. Guide sign of natural ecosystem conservation area in Mt. Daedeok and Geumdae Peak

Even though natural environment of the Baekdudaegan has not been well known due to insufficient survey data, it is certain that the Baekdudaegan is a treasure house and source of natural habitat with abundant and various species of fauna and flora (Korea Forest Service 1997). According to the ecosystem survey (Ministry of Environment 2001) in 1990 carried out along the mountain ridge of

680km from Hyangro Peak to Jiri Mountain, it was revealed that 1,326 species in 120 botanical families inhabited there. Among them, 109 spicies indigenous to Korea were growing wild throughout the Baekdudaegan and various kinds of fauna and flora were gound growing in colonies such as Carpinus laxiflora and Abies koreana wils. The surveyors witnessed rare mammals, birds and amphibia, which proved that the Baekdudaegan is the last hideout for wild animals to resort to under the situation that poaching for wild animals is prevailing nationwide. It is known that natural monuments or species indigenous to Korea and highly worthwhile preserving such as musk, goats, martens, Eurasian small flying squirrels and Asiatic black bears are living in the Baekdudaegan.

3.1.2 Social and Cultural Environment of the Baekdudaegan

The living realms and local culture of the Korean people are formed along the Baekdudaegan. Even in small number of exceptions, [12] the ridgelines of the Baekdudaegan are correspondent with administrative boundaries. There are 6 provinces, 12 cities and 20 counties[xiii] along the Baekdudaegan, forming 27.5% (27,313 ㎢) of national territory (Ministry of Environment 2001).

Figure 12. A closed school in a ridge of the Baekdudaegan

Most areas around the Baekdudaegan are forests, but there are some areas developed for various purposes: new settlements were established on the hills and some forests were exploited by development projects (Ministry of Environment 2001) during the period of Japanese rule, and recently the natural environment of the Baekdudaegan is severely deteriorated due to development such as high-altitude vegetable cultivation, public cemeteries, land under cultivation, leisure facilities like skiing grounds, road and railway construction, mine development, etc.

Figure 13. An excavated mine in Mt. Johang

There are “Cheonjedan” for performing a ritual to the sky and “Seonangdang” for performing sacrificial rites for a tutelary deity, which are folk and culture remains showing local characteristics, and old boundary gates are located in passes and high hills, explaining that the Baekdudaegan was used as defense lines in wartime as well as boundaries of districts.

3.1.3 Current Development Situation of the Baekdudaegan

There are three types of development activities deteriorating the environment of the Baekdudaegan,[xiv] which are categorized into three types of point (Ministry of Environment 2001), line and side according to the scale of facilities and their affects: firstly, the point-type developments include about 20 power-transmission towers, telecommunication facilities, observation posts, which are located in ridgelines and have bad influences on landscape values and natural environment. Secondly, as the line-type developments tens of roads and railways have been constructed across the ridgelines, thus impairing the quality of landscape and ecology of the Baekdudaegan. And the side-type developments are related with living facilities such as farm lands and building lands, public facilities like dams, leisure facilities for ski and golf, and mine fields, which are considered as most major factors affecting natural environment. Besides these, some military facilities are located around the Baekdudaegan.

Most facilities around the Baekdudaegan are evidently interfering with ecosystem from the perspective of nature, and on the other hand, some of them could be beneficial to humankind since the Baekdudaegan is playing a role of the safe corridor for living creatures, but it could be obstacles for east-west interchange of people. In this regard, it is imperative to install power-transmission towers and to construct roads, but we have to be more careful to select sites for this kind of facilities and to decide the construction methods. But in cases of dam or leisure facilities construction and mine development, we should give careful consideration to the establishment of large-scale facilities such as dams, leisure facilities, mines, etc.

3.1.4 Legally protected area around the Baekdudaegan

Because of ecological importance, the Baekdudaegan is currently managed by several types of preservation zones including several national parks,[xv] two provincial parks, two ecosystem preservation areas to protect important ecosystem around Jiri Mountain and Daeam Mountain and four natural protected areas[xvi]. Some parts of Seorak Mountain are designated as biosphere preservation areas by UNESCO and in addition, there are 56 natural nurse forests to keep vegetation growing in colonies.

Besides this kind of areas, which are designated and managed by single acts, there are different kinds of areas that are appointed for other purposes by individual laws. For example, some parts are designated as protected water areas, wildlife protected areas, forestry promotion areas, etc. and managed by other laws. In particular, national forests in the Baekdudaegan are managed by Korea Forest Service for the purpose of forest and seed production and forest experiment.

3.2 Management status of the Baekdudaegan

The Baekdaegan is currently managed by Ministry of Environment, Korea Forest Service, and local authorities. The Ministry of Environment is approaching the Baekdudaegan from the perspective of natural environment conservation, and Korea Forest Service is managing it for forest protection. But each concerned local

authority doesn't have any specialized strategies to manage the Baekdudaegan besides following individual laws. It is the fact that local authorities are rather interested in establishing leisure facilities exploiting well-preserved natural environment and undeveloped mountains and hills.

Figure 14. Lco-bridge in Guryeong reyong (pass)

Since the late 1990s public concerns have been increasing, including the demand that certain areas around the ridges from the Baekdudaegan should be preserved and the Ministry of Environment has begun to consider the suitability of development projects to the environment. With the lack of objective criteria for the designation of special zones, the Ministry of Environment firstly designated the areas within a horizontal distance of 700 meters from the both banks of the ridgelines of the Baekdudaegan as special management zones in 1999 and established procedures to get approvals for any development or land use. Major development projects within this special management zones should be examined whether they are appropriate for the environment. In fact, this kind of measures could induce various projects into pro-environmental directions and prevent the establishment of some inappropriate facilities for the environment, but they are not taking into account the natural environment and cultural and social features, showing problems in demarcating a boundary for the management of the Baekdudaegan. In particular, since the Baekdudaegan is forming the landscape with continued forestry patches of various scales and also is playing a role of individual patch (Ministry of Environment 2001) in the Korea peninsula, it is necessary to consider the influence of the installment of one facility, which would deteriorate the environment of other areas besides its located place.

The Ministry of Environment has interest in the Baekdudaegan because as a treasure house and source of natural habitat, it is found to be an eco-corridor of wild animals and important vegetation zone. Therefore, the Ministry regards the Baekdudaegan as an axis of national eco-network and promotes management policies for natural environment to maintain ecosystem. In this regard, since 2000s the Ministry has been carrying out a plan to develop concrete measures for management, and to prepare for institutional devices as well as to demarcate a boundary (Ministry of Environment 2001) for management taking into account the natural environment and cultural and social features.

Korean Forest Service (1997) has been interested in the Baekdudaegan since the mid 1990s. It has made efforts to research and manage forest resources around the Baekdudaegan. It ordered the Korean Geographical Society to conduct the "Survey on Current Status of the Baekdudaegan and Its Definition" in 1996, and published a series of survey reports on the Baekdudaegan.[xvii]

Korea Forest Service has played a role of a manager for the Baekdudaegan and its forests, such as forest fire prevention, forest extension, deforestation, etc. As of recent, along with rising environmental issues and the importance of the Baekdudaegan, it endeavors to analyze current conditions of the Baekdudaegan as well as to establish and develop institutional basis for strengthening regulations related to forest development projects.[xviii]

Before moving into formal management, we need to examine some problems in managing the Baekdudaegan in cases of the Ministry of Environment and Korea Forest Service: firstly, each authority related to the Baekdudaegan has different purposes for the management. Because of its locational, geographical and biological characteristics, the Baekdudaegan has controlled by various individual laws and authorities. Secondly, the geographical range of the Baekdudaegan has not been defined yet. Thirdly, there is no measure to restore destroyed lands or ecosystem of the Baekdudaegan due to the development projects. Fourthly, it is difficult to promote management policies consistently because of conflicts between related authorities. On the one hand, there are authorities for the conservation and management of the Baekdudaegan, such as the Ministry of Environment and Korea Forest Service, and on the other hand, there are authorities for the development and utilization of the Baekdudaegan, such as the Ministry of Commerce, Industry and Energy, and the Ministry of Construction and Transportation. In particular, since the Ministry of Environment and Korea Forest Service are competent authorities to manage the Baekdudaegan, relevant local authorities suffer difficulties in deciding which division should manage the Baekdudaegan.

3.3 Current Issues in Managing the Baekdudaegan

3.3.1 Colleting Basic Information on Current Conditions of the Baekdudaegan

The Basic information on the Baekdudaegan are categorized into natural environment related with flora and fauna, land features, etc. and damaged status of mountains due to facility construction or development projects. The previous surveys on natural environment conducted along the ridgelines were not adequate to analyze ecological features of the Baekdudaegan. With the first and second surveys on national natural environment of the Ministry of Environment, it is possible to examine comprehensively natural environment of the Baekdudaegan. However, as we have not defined the geographical range of the Baekdudaegan, we cannot decide which regions around the Baekdudaegan would be surveyed for natural environment researches. With the surveys of the Ministry of Environment, which were carried out in a limited area, it is difficult to analyze natural situation and characteristics of the Baekdudaegan. Especially, since the research objects are mostly related with recording species and numbers of flora and fauna, the survey results are not enough to study structures and changes of ecosystem of the Baekdudaegan. Therefore, it is desirable to conduct future researches focusing on ecosystem with the examination on relations between species of plants and animals and between landscape components.

We have surveyed on external status of destroyed mountains and now we need to research changes of surrounding environment due to facility construction and development projects and collect information to consider feasibility of the construction and other possibilities (Dale *et al*. 2001). Some civil organizations for environmental preservation carried out surveys on destroyed conditions of the ridgelines, which also focused on the external status, and it is required to comprehensively research surrounding environment and factors to cause destroying mountains. However, these surveys and activities conducted by environmental organizations are found out to be significant for the study on the Baekdudaegan. In particular, when their activities and researches have been known to the public, the government as well has been interested in preserving the Baekdudaegan and attempted to manage it with administrative and institutional measures.

3.3.2 Promoting Comprehensive Management Policies for the Baekdudaegan

We have managed the Baekdudaegan not with comprehensive strategies or long-term plans but with individual countermeasures against various development projects. It is because any long-term goal for the management and geographical range of the Baekdudaegan has not been defined yet (Ministry of Environment 2001).

There are mostly forests around the ridgelines of the Baekdudaegan with various locational, geographical, and biological features, thus being controlled by a number of related laws. The protected areas around the Baekdudaegan are designated for different purposes and managed by different authorities, resulting in difficulties in consistent management (Dramstad *et al.* 1996) of the Baekdudaegan.

In addition, it is not decided which authority manages the Baekdudaegan as a competent Ministry, especially causing conflicts and confusion between the Ministry of Environment and Korea Forest Service. It brings lots of difficulties in promoting conservation and development of the Baekdudaegan due to differences in their interests. In the situation without any concrete measures for the management, the necessity of the conservation is only emphasized. The relevant local authorities are promoting development projects with relatively well-preserved natural environment around the Baekdudaegan. We have concentrated on environment destruction due to facility construction, but we need now to establish strategies to cope with the construction of tourism facilities in the name of regional development plans.

3.3.3 Establishing Institutional Basis for Efficient Management of the Baekdudaegan

The Baekdudaegan is related with a number of laws such as the Act on the Utilization and Management of the National Territory, the Forestry Act, the National Parks Act, the Framework Act on Environmental Policy, the Natural Environment Conservation Act, the Protection of Cultural Properties Act, etc. The fact that there are many related laws with the Baekdudaegan is not found to be a problem. However, each authority with its own policy direction and management objectives is controlling each area with similar conditions with individual laws, thus making difficulties (Ministry of Environment 2002) in efficient management of the Baekdudaegan. The complexity in relevant administrative and institutional systems

impedes the cooperation between authorities and generates problems in deciding which authority should cope with matters related with the Baekdudaegan.
With increasing necessity of the conservation and management and demand for development of the Baekdudaegan, it will become more difficult to manage it in a consistent way due to the conflicts between relevant individual laws. It is required to promote adaptable and flexible management policies for Baekdudaegan considering various conditions in each region around the Bakedudeagan. And it is important to establish institutional systems for integrated management of the Baekdudaegan, so as to efficiently execute the management policies.

4. BASIC MANAGEMENT DIRECTION OF THE BAEKDUDAEGAN

Under the consideration of current condition and issues as well as the significance of the Baekdudaegan, the management strategies of the Baekdudaegan are suggested with its management purposes and basic principles.

4.1 Management Goals of the Baekdudaegan

To propose management directions of the Baekdudaegan, it is imperative to set management goals definitely (Agee *et al*. 1988). Due to the lack of information related to Baekdudaegan, it is impossible to make concrete, practical and measurable management goals even with the data introduced above. It is desirable to collect information on the management status of different kinds of protected areas, situation of damaged mountains, and current conditions of wildlife to determine management directions.

The proposed management goals (Ministry of Environment 2002) in this study are "reestablishment of traditional concept of the Baekdudaegan," and "conservation of natural environment of the Baekdudaegan." The first goal is to preserve traditional concept of the Baekdudaegan, which is treasured in the Korean people's hearts and is playing a role of the central axis with one Jeongan and thirteen Jeongmaek. For the reestablishment of the traditional concept, the ridgelines of the Baekdudaegan should be protected and maintained. Existing development projects have been conducted along separated ridgelines of the Baekdudaegan, disregarding the traditional concept based on the premise that all the mountains in Korea make one ridgeline. In this regard, the traditional concept reestablishment and the natural environment conservation could finally become one management goal.

The second goal is to conserve natural environment of the Baekdudaegan from the landscape ecological perspectives. It is possible to enhance habitat for a variety of species (Forman and Godron 1986) by preserving surrounding natural environment of the Baekdudaegan, and then if the ecosystem of the Baekdudaegan operates properly, it will function as one of national ecological axes. Therefore, it is required to protect major natural environment against various development projects. We should decide whether to limit development projects in consideration of all conditions of the Baekdudaegan, so as to prevent destroying environment and impairing the flow of ecosystem as well as to provide necessary facilities.

From the historical and cultural perspectives as well as the landscape ecological perspectives, it is expected to enhance the quality of people's life based on emotional and natural abundance with the reestablishment of traditional concept of the Baekdudaegan and the conservation of natural ecosystem.

4.2 Basic Principles of the Management of the Baekdudaegan

4.2.1 The Principle of the Harmonious Coexistence of Nature and Mankind

The management of the Baekdudaegan does not mean the unconditional prohibition of development projects. Since it is a fact that the Baekdudaegan is an obstacle for human activities due to its geographical features, we should accept the "activities" for our needs. Before constructing necessary facilities, it is important to carefully examine the effects (Overbay 1992) of the construction on the ecosystem of the Baekdudaegan. In order to analyze how these activities affect the concept of the Baekdudaegan and biological resources, it is necessary to collect information based on accurate researches on the Baekdudaegan.

4.2.2 Respect for the Nature's Intrinsic Value

In the existing Dominant Scial Paradigm (Catton *et al*. 1980), interests of mankind have been considered before the effects of natural resources use on the ecosystem, because we have believed that advanced science and technology could solve the problems resulting from environmental destruction and contamination. However, in the New Environmental Paradigm (Catton *et al*. 1980) of the 21st century, ecological sustainability is regarded more important than economic efficiency. This paradigm (Dunlap and Liere 1978) respects nature's intrinsic value and insists that every human activity should be conducted in consideration of nature's value (Bengston 1993). The traditional concept of the Baekdudaegan and its natural environment should be preserved in this ecological paradigm. In this regard, all development activities are required to be allowed when the value and relationship of all ecological components are protected (Agee *et al*. 1988). We need to decide whether to limit development activities under the consideration of the fact that we are not superior to nature and we are a part of it (Dunlap and Liere 1978).

4.2.3 Righteous Use of Natural Resources

We have used natural resources with the principle of "wise use," which values the sustainability of natural resource production for mankind, rather than the sustainability of nature itself (Devall and Sessions 1985). Because of this way to use natural resources focusing on mankind's interest, our natural resources have been depleted and our natural environment has been destroyed, but we have thought these problems as an unavoidable reality and have not attempted to cope with them in advance. However, in the principle (Devall and Sessions 1985) of "righteous use"[xix] of natural resources coming recently from the ecological perspectives, sustainable development and prevention of environmental problems resulting from natural resources use are emphasized. All the development projects around the

Baekdudaegan should be carried out considering the effects on the environment from the initiative stage of the projects, so as to handle possible problems in advance.

4.2.4 Coordination and Agreement

There are natural resources with relatively high biological diversity and lands developed for various purposes in the Baekdudaegan, as well as tens of related laws and authorities, generating conflicts between stakeholders such as residents, landowners and local authorities. Since the stakeholders have difference of opinion on the conservation, development and utilization of the Baekdudaegan, the coordination and agreement between them are important factors (Choi and Cho 2002, Creighton *et al*. 1983) in deciding management directions. In this regard, the most important thing is the process to establish conservation and management strategies. When promoting institutional development for the Baekdudaegan in the future, we should consider the social and regional equity with the stakeholders' coordination and agreement (Overbay 1992).

5. EFFICIENT MANAGEMENT STRATEGIES FOR THE BAEKDUDAEGAN

What we have to do for the conservation and management is, firstly, to decide the geographical range of the Baekdudaegan, in order to research and examine its current situation. It is expected to analyze biological and cultural features and to suggest concrete management strategies for the Baekdudaegan (Ministry of Environment 2001). Secondly, planned strategic approaches to the management of the Baekdudaegan are necessary to be promoted systematically, asking for long-term plans (Ministry of Environment 2002) for the Baekdudaegan as it is. Thirdly, it is imperative to establish institutional basis for the conservation and management the Baekdudaegan.

Figure 15. An example of management scope of the Baekdudaegan

5.1 Preconditions for Efficient Management of the Baekdudaegan

5.1.1 Establishment of management scope of the Baekdudaegan

We have not obtained useful research information on the Baekdudaegan to suggest efficient management strategies since we have not decided geographical range of the Baekdudaegan.[xx] When the geographical range

for the management of the Baekdudaegan is decided, more concrete and practical strategies could be established and surveys for various purposes carried out. The information on the Baekdudaegan acquired by surveys will provide strategic basis for conservation of biological resources and will be used to analyze environmental impact of development projects. In addition, it is expected to built national land plans with a geographical view based on the Baekdudaegan as a foundation of national territory.

The most important thing to consider when we decide the management scope of the Baekdudaegan is to preserve its traditional concept and to pay due regard to connectivity and consistency (Naveh and Leiberman 1993) between components of. First of all, in order to adapt the idea to regard the Baekdudaegan as one connected system of mountains, Marugeum(ridgelines) and groups of mountains consisting of the Baekdudaegan are required to be included to the management scope. In this regard, the management scope is desirable to contain all the lands adjacent to the Baekdudaegan including damaged parts due to development projects. Secondly, in order to maintain the Baekdudaegan for the coexistence of mankind and nature, damaged lands and villages around the Baekdudaegan are necessary to be included to the management scope. We need to consider the connectivity between components of ecosystem, such as forest patch across ridgelines of the Baekdudaegan, so as to mitigate the impact of development projects on the environment. Thirdly, it is required to reflect opinions of concerned local authorities, residents and experts in planning stage of the management scope for coordination and agreement of the interested parties. Fourthly, we need to have in view the fact that natural environment centering upon the ridgelines of the Baekdudaegan is a source of natural habitat, composing one of ecosystems. In other words, the ecosystem of the Baekdudaegan is one portion of ecological systems as well as a group of components of the ecosystem, which establishes a partly independent and partly dependent environmental system (Naveh and Lieberman 1993). It should be emphasized that the Baekdudaegan has affected the quality and diversity of natural environment of the Korean peninsula when its management scope is decided.

5.1.2 Establishment of efficient management strategies

It is imperative to propose management directions in the comprehensive and long-term perspectives for efficient management (Choi and Cho 2002) of the Baekdudaegan. It will be more desirable to promote individual development projects and conservation activities within a whole frame of the long-term management of the Baekdudaegan.

It is important to manage the Baekdudaegan with strategies and measures appropriate to the situation of each region under one unified principle (Choi and Cho 2002). In this regard, it is most urgent to establish the management strategies (Choi 1995). All sorts of components included into the management scope of the Baekdudaegan are to be examined in the process of comprehensive planning. In particular, the management of ridgelines and national forests, the construction of various facilities in accordance with individual laws, and inconsistency of regulations applied to existing protected areas and the other areas should be

seriously considered when establishing the management strategies. In addition, it is necessary to establish comprehensive strategies for the management of the Baekdudaegan looking into the fact that it has various characteristics of natural environment, and social and cultural aspects, as well as all kinds of interested parties (Choi 1995, Twight and Lyden 1989). The management strategies are to propose concrete plans to manage protected areas designated in the Baekdudaegan, to control forest management, rearrangement of mountain villages and development activities, and to maintain a healthy ecosystem.

The management strategies are to be divided into two parts (Ministry of Environment 2002); "Management Framework Strategies" for the Baekdudaegan as a whole, and "detailed management strategies of local authorities." The framework strategies are to propose the management principles, goals and plans, thereby providing basis of detailed management strategies.

5.1.3 Establishment of institutional basis and cooperation system between relevant institutes

The regulations related with the Baekdudaegan are found out to be about 50-60. Ecosystem preservation areas, natural parks, protection forests are designated and managed by individual laws, and development projects and activities are also regulated by such laws. As a result, even specific regions with similar natural environment have controlled by different regulations, and therefore, consistent institutional systems are needed to be established, so as to decide geographical range for the management of the Baekdudaegan and to propose the management strategies.

The institutional improvement will be conducted with the amendment of individual laws or the enactment of new regulations on the Baekdudaegan, required to formulate the management scope and plans as mentioned earlier. In case of the amendment of existing regulations, the Natural Environment Conservation Act and the Forestry Act could be suggested as a legal basis. Considering the difficulties in building institutional foundations for the management of specific areas by revising existing legal systems, and ecological, geographical and traditional significances of the Baekdudaegan, we need to be careful to check if the amendment of regulations is in accord with the existing legal systems. In this regard, we cannot say that it is desirable to formulate a special law for specific regions and specific purposes, but it could be more efficient measures to establish legal foundations for the management of the Baekdudaegan by enacting new regulations.

The cooperation of related ministries is related directly with the success of the management policies for the Baekdudaegan (Choi and Cho 2002). The Ministry of Environment in charge of natural environment preservation and Korea Forest Service for forest management have different positions toward the management of the Baekdudaegan, thereby asking for constituting a committee for coordination and agreement between them. The role of Korea Forest Service is especially important for efficient management of the Baekdudaegan because it is responsible for the management of national forests covering ridgelines and most parts of the Baekdudaegan. And the Baekdudaegan is required to be maintained for the

conservation of the ridgelines and surrounding natural environment as well as for forest management.

5.2 Management Strategies

5.2.1 Basic Directions of the Management Strategies

The management strategies to maintain the ridgelines and natural environment of the Baekdudaegan should be made in the consideration of various related fields from several viewpoints, because it will be difficult to suggest efficient management strategies without comprehensive researches and surveys on the Baekdudaegan. Therefore, more detailed and definite strategies are expected to be proposed when all the issues regarding the natural and environmental features, and development activities of the Baekdudaegan are extensively examined, as well as manpower, structure and budget of an organization in charge of the management of the Baekdudaegan. Taking these limitations into consideration, this paper presents the management strategies based on the issues regarding the management of the Baekdudaegan, management goals, current status of regions destroyed by development projects, institutional system related with the management scope, and the management principles.

It is most important (Dale *et al*. 2001) to restrict natural environment from changing due to development activities as far as possible. And conservation takes precedence of development in principle when conflicts between them happen. In this regard, it is more important to encourage people to conserve and maintain the Baekdudaegan with the concept of its significance than to manage it with regulations. We should strive to carry out research and survey on history, culture and landscape ecology of the Baekdudaegan, providing all information on the Baekdudaegan to the public.

5.2.2 Consideration ecological features and management aiming at landscape protection

It is difficult to propose concrete measures to protect landscape without researches on the Baekdudaegan at this point of time. Comprehensive researches need to be conducted on landscape features and wildlife in the management scope of the Baekdudaegan to analyze the connectivity between ecological components. For the purpose of maintaining healthy ecosystem in specially protected areas, it is required to survey specific species selected for monitoring and to decide management directions. It is desirable to select the species for monitoring among the middle class of a food chain rather than among species at extinction risk, so as to survey conditions of habitats according to environmental changes (Naveh and Lieberman 1993).

In the meantime, the protection of scenery following the various facility installations, it is more desirable to consider the scenic structure and the impact on the functions by the facilities rather than focusing on harmonizing the facility with the scenes of visual level. The Baekdudaegan possesses a variety of topography and

plant growing zones that the appropriate management on the regional characteristics is important. For example, the scenic protection in the alpine region has to be differentiated from other areas. The alpine region is an important space that has to be preserved first for the ecological soundness since most of the area possesses important clinical characteristics, and it shall control the promotion of various development projects as much as possible unless the project is inevitable nationwide (Forman and Godron 1986). Along with that, in the areas with high preservation value, the fragment of ecology shall be controlled not to occur by the artificial facility installation or activity such as road construction, cultivation, deforestation and others. In addition, the area where a protection is needed but has already been damaged shall recover the original appearance through the ecology restoration and others.

5.2.3 Seeking of Measures for damages in the point of view of landscape ecology

Damages done unto the Baekdudaegan by the development and use of it shows visibly, but the effect and change on the ecological factors are not visible to the bare eyes or find out in short period of time. The changes by such an environmental impact (Dale *et al*. 2001) may be found generally in soil, water quality, plant, wildlife and scenery. With the changes of each factor to come together to bring the change of functions and the structure of landscape, and this in turn shows as the future of the Baekdudaegan. Accordingly, in order to seek the measures on the environmental damage by the various development and use, there is a need to look at the factors mentioned earlier.

In addition, we shall not overlook the point that the natural environment may change (Forman and Godron 1986) due to the development and utilization. Even small-scale development and utilization projects can effect on our natural environment that we should develop the attitude to accept only the minimal damage to the environment by the development. However, it is important to focus on the management on how much to permit and what type of after action to take for maintaining the permitted measure.

In order to seek the action for damages under such a point of view, it is more important to continuously find out the degree of ecological impact of the damaged area and its surroundings than anything else (Naveh and Liebeman 1993). Sometimes, there is a part requiring the observation of the changes following the changes or leaving it alone instead of establishing the artificial restoration action. If the damaged part requires a long time of observation and it effects negatively due to the wrong development and utilization currently, the work on the future development or utilization would be more urgent than the restoration measures on the areas of damages. The desirable thing is to pursue the survey on the damaged area as well as the policy to lead various development plans into the right direction.

Accordingly, the action on damage shall be based on the thorough survey (desirable thing is to implement continuous survey, not a one-time survey, and find out the seasonal change and others) on the impact of development and use for the purpose of reducing the other environmental impact caused by the actions of the damages (Cole 1982). At this time, the survey shall be implemented on the

surrounding area (part that is determined to have the relativity environmentally) including the site of the damage. In addition, the survey shall be performed on the phenomenon of landscape disconnected by the facility installation, water pollution following the construction, discharge of environmental pollution following the facility usage and the destruction of subject site and surrounding habitat for plants and animals in the area. On the effect following the frequent use of the users on certain zone, the pressure on soil and ensuing moisture absorption rate, degree of damages for surface soil, removal of root and plant on the ground, inflow of waste, damage to the plant by the intentional act and others are to be surveyed. However, the structure and function of landscape is not to be determined with the survey result of each factor. With the result surveyed for a significant period of time, the mutual factors and the change in ecology shall be sensed, and even if such an analysis is made, the problem is that it cannot be determined as the result of development and use. For example, when the activity of wild animal is influenced by the installation and use, the wild animals change the habit due to the stress from the interference of their normal life (Cole 1982). As the result, it may consider that there are various showing including the type to move the habitat, type to adopt, the type to extinct and others, and in addition, even if for the same type, they show different phenomenon in accordance with the degree of impact, disconnection degree and others (Forman and Godron 1986).

The thing to be aware of during the course of survey or interpreting the result is that the managers always have the critical position on the damages at all times. Namely, the manager shall not seek the actions on damages for more than necessary with the overly negative view on the result of natural environment damages. It is because such a consciousness is an excessive management action that the change in the nature itself is highly like to be determined as the artificial result.

5.2.4 Suggestion of policy directions regarding various developments and installments

In reality, areas used for developments and facility installations do not compromise the general environment of the Baekdudaegan, however, aforementioned facilities destroy its ecosystem and can negatively contribute to wildlife. Accordingly, it is desirable to make decisions in consideration of facility type and its adjacent environment, not of its size or damaged areas. Particularly, elaborate review of impacts of developments and facility installations on surrounding lands and environment is crucial. As a result, approval will be based on facility type, size, location and changes that will bring about to the environment. In circumstances where facility is of identical type, size and location, developer's plans concerning environment during facility installation, restitution plans and policies can be a determining factor for approval. If facility is small in size but impacts negatively on

Figure 16. Yangsu Dam in Mt. Jiri

the environment, it will be unfavorably recognized. In order to maintain concept of the Baekdudaegan and preserve ridgelines that symbolize it, the Baekdudaegan will be protected from various developments.

In accordance with environment protection and maintaining the concept of the Baekdudaegan, any development and installation will be based on four criteria (Riedel and Lange 2001) of management policies. First policy is "unacceptable." Only those that are inevitable from a national perspective will be permitted. Aforementioned policy intends to avoid any negative impact before hand. Second policy is "reduction" and "compensation." Development process will be given partial permission based on restoration plans. In conditions where development is inevitable, plans for reduction and compensation will be required. In order to protect environment, evaluations from monitoring and review of plans to alleviate environment damage will be required. Pursuant to "reduction" policy, its intention is to reduce any negative impacts to a minimum. Third policy is "replacement." When recoverability is not feasible, despite the need for development, replacement of lost environment will be required in order to progress with the project. Precisely, if damage to environment is not recoverable as a result of development, equivalent expenses will become liable to the developer. Fourth policy is "removal." For those development that has materialized and in operation, which negatively impacts environment will be removed. In addition to the removal, subsequent restoration will be performed.

5.2.5 Establishment of management policies considering regional differences

In response to manage the Baekdudaegan, the scope of its geographical range was proposed. Accordingly, considering lengthy ridgelines of the Baekudaegan and spacious adjacent area, the extent of coverage is expected to be comprehensive. As a result, it is not practical to manage it based on single criteria. To resolve aforementioned difficulty, this report serves to review dividing the regions based on regional differences.

It is essential to consider connecting adjacent ridgelines, physical properties and biological properties (Agee *et al*. 1988, Dale *et al*. 2001). Managing resources suitably based on its uniqueness will encourage people to act appropriately. Eventually, place where people and nature can coexist in balance can materialize. Ridgelines of the Baekdudaegan act as the important notion dividing point of different regions. District division can be done in various forms. For example, it can be divided into core area, buffer area, and transition area (Western and Pearl 1989).

Core area consists of superior environment (unmodified natural environment) and adjacent ridgelines. Buffer area consists of regions with natural environment and intervened environment. Transition area consists of regions with high development impact, great human presence and high potential for development (modified natural environment).

5.2.6 Consideration on Local Residents and Land Owners

To be reduced the negative impects of the Baekdudaegan management, the separate regulation on the private land shall be minimized (Choi 1995). The actions for sustaining the ecological system and achieving the Baekdudaegan management objectives shall be taken not to incur damages to the private landowners along with the preparation of systematic basis. Accordingly, the private land that is required on management shall be taken over as the national land fundamentally. For this purpose, the review shall be made in terms of purchasing the private land or exchange with the national land and others. In addition, for a part of private land, the manager may enter into the lease contract with the landowners to resolve the problems of management and action restrictions in advance. In addition, there is a possibility of reviewing the plan to comprise the management committee through the stipulation on the interference of private right, restriction of action and others caused by management, and at this time, the participation of local resident shall be guaranteed in the committee structure (Creighton *et al*. 1983, Twight and Lyden 1989).

The purpose of managing the Baekdudaegan is to sustain the concept and natural environment of the Baekdudaegan (Lim 1999). In the concept of the Baekdudaegan, it contains the life of local residents in the point of view of history and culture. Accommodating the local residents is a part of the Baekdudaegan management. Accordingly, the installation of necessary facility or artificial action to undertake the existing residential living shall be desirable to sustain as much as possible (Butler 1998, Choi 2001). When the Baekdudaegan management is fully undertaken, there has to be continuous communication and providing of information for keeping the local residents from having the concern of control for regional development and limitation on land use. In particular, gathering of forest products, normal cultivation activity, housing construction and others shall be guaranteed. In the meantime, when there is a need of restriction of use including the agricultural chemicals, insecticide, chemical fertilizer and others, the support plan shall be prepared on the reduction of productivity.

With the Baekdudaegan management, the regional development projects of the applicable local government may be controlled. In the event of public projects, the characteristics of the Baekdudaegan on the selection of position, development method, development size and others shall be considered, however, the progression of the project shall require to be continued. However, the tour development project that each local government pursues fiercely shall be promoted seriously. The establishment of resort facilities such as golf course, ski resort and others, and various accommodation facilities requires the consideration on the negative aspects rather than the positive aspects. These tour development projects may have the effect on regional economic point of view including the hiring of local residents, activation of accommodation and commerce, outstanding accessibility between region, increase of local tax incomes and others. Conversely, it may have the negative impacts such as the outflow of young generation from the local residents, loss of local tradition following the inflow of tourists and added insecurity of the local sentiment, and release of environmental pollution. In the event that such a situation is accurately presented to the local residents, the selection of the local residents may

more seriously be made. Accordingly, rather than interfering with the regional development with the restriction on some developments by pursing the Baekdudaegan management policy, it has larger advantage in continuously maintaining the well preserved natural environment as well as the tradition. If the local governments activate the ecology tourism by utilizing such strengths, it may prevent the exposure to the damages with the promotion of the Baekdudaegan management policy. Under the circumstances, the central government and local government shall seek the action plans to resolve the problems on economic losses arising from controlling the regional development due to the facility regulation and action restriction. Important thing is that there is a need of review on what type of economic sanction is to receive, and in the event of requiring the review, the support plan on applicable local government shall be considered.

5.2.7 Implementation of Steady Survey for Preparing the Detailed Management Method

To prepare the detailed method of the Baekdudaegan management, structuring of base information is very important. Accordingly the survey is steadily and regularly made for the matters related to organism, culture and history on the scope of the Baekdudaegan management to accumulate the basic data. The survey on organism may utilize the result of basic survey of national environment that is currently implemented now. However, there is a need of sufficient review on survey period, survey method and recording method and others. Here, it includes the matter to make comprehensive determination of the forestry condition, and it may be possible to promote with the cooperation of pertinent departments on the survey and air-photo reading prepared in relations to the clinical chart.

Culture related survey includes the matters to find out the regional characteristics for each area. In particular, through the survey on the lives and culture of people residing here, it may be utilized as the basic data in establishing the implication of the Baekdudaegan. In addition, for each region, the survey shall include the ceremony, tradition, and geomancy point of views related to mountains that include the Baekdudaegan. For a matter related to history, it includes the arrangement and survey on the land history that effected or is effecting on the region by the ridge of the Baekdudaegan, and it arranges various subject matters that have been handed down from the major historic sites and people.

Such a base survey would be more desirable to promote by supplementing the survey matters or utilize the base survey on the national natural environment currently implemented or separately implemented. For the Baekdudaegan management, the matters related to the monitoring on the necessary survey items and management shall be added. In addition the Baekdudaegan, once the scope of management is determined, the survey period is adjusted to make the survey on entire districts in systematic way. The survey result is made for database and prepare in drawing to have the regional changes to be used in the next management plan.

In addition, the surveyed matters are not only prepared on the list but required to make it in drawing as well. Once the survey contents on aforementioned organism, culture and history are tied in one to make a map, it may take the role of

comprehensive map on the Baekdudaegan, and it will be useful in establishing the detailed plan of the management based on it. Such a map is referred to as ecology culture map and it includes the status of use, condition of damage, distribution of local resident, development type and others. As such, the ecology culture map of the Baekdudaegan not only pursue the management policy and establish the management plan but also to take the role to inform the information on the Baekdudaegan to people.

6. CONCLUSION

When the Baekdudaegan is to preserve and manage, the important thing is to think what the Baekdudaegan means to us. The decision on what the Baekdudaegan means to us, where does the Baekdudaegan stand in our land, and what is the role it takes on our environment are the cores in setting the Baekdudaegan management policy direction. Looking into the result [xxi] that inquired on the importance of the Baekdudaegan by the Korea Research Institute for Human Settlements (2002), respondents reply that the Baekdudaegan possesses the habits for major wildlife and rare organism that it is important to us. Along with the same vein, people think that the Baekdudaegan is very important due to its symbolism of the root of the people's spirit. People grant the existential implication in the organism point of view under the conceptual point of view on the Baekdudaegan.

Preserving and managing the Baekdudaegan since it is important under the biological point of view has clear concrete subject and objective that the direction for management is easily established. However, managing the Baekdudaegan since it is the root of national sentiment has ambiguous management subject that the establishment of management direction is rather difficult. It is because the root of our ethnic sentiment for the Baekdudaegan is understood as a conceptual thing simply without the practical body. In fact, the Baekdudaegan expresses the geographical feature that influenced greatly on our living norm and culture, and as the result, it shall be deemed as the practical body that has profound relationship with our sentiment. However, Baekdu Mountain has been believed to be the place where all spirit of land began under the national ethnic consciousness that worshipped mountains. Such a geomancy point of view has mingled with the practical geographic effect that the Baekdudaegan has its place within the unconsciousness.

Now, the Baekdudaegan shall be deemed as the concept expressing the basic consciousness of our people on land and has to be deemed as the practical body within it. Mountains, taking most of the land, are mutually connected and it has the order within them. Therefore, the entire land is connected in one line of mountains. The mountains have the mutual relationship with the water lines and are systemized. Such a fact is the reality of 13 Jeongmaek that includes the Baekdudaegan. The Baekdudaegan may be a result of wisdom of our ancestors who viewed the land as an organizational body. In the contemporary meaning, the Baekdudaegan has the same vein with the efforts to see the land in landscape ecological connectivity (Dramstad *et al*. 1996). Seeing the land under the landscape ecological point of view

is to illuminate the use on nature of human and the value in nature itself as well as the change of nature itself. The understanding on the Baekdudaegan can be said to have the same flow with such a development.

Recently, when discussing the land, the concept of sustainable development has been widely used. Sustainability means the sustaining of natural environment while the nature is used to accept the demand of the society (WCED 1987). Recently, before the nature of the Baekdudaegan is damaged, our culture and life have been harmonizing with the nature of the Baekdudaegan. The Baekdudaegan is the place where the change of nature and formation of culture are reconciled. Maintaining the Baekdudaegan has to be the objective of the Baekdudaegan management. Ultimately, this is the time to have much more understanding for the Baekdudaegan, which becomes the space where human and nature coexist.

7. NOTES

i "Daegan" means literally a large mountain range

ii The Goryeo Dynasty's history, 1454.

iii These three books are all geographical records of the Korean peninsula

iv "Honil Gangri Yeokdae Gukdo Jido (Map of the integrated lands and regions and historical countries and capitals, 1402)," "Honil Yeokdae Gukdo Gangri Jido(Map of historical countries and capitals and the integrated lands and regions, mid of 16th century)," "Dongguk Daejeondo(Grand map of the Eastern State,1757)," "Yeojido(Grand Map, end of 18th century)," etc.

v The oldest surviving world map from East Asia, made by Kim Sahyung, Lee Moo and Lee Hui in 1402. Its total dimensions measure 164×171.8 cm. It is no longer preserved in Korea itself and its copy is in the Ryukoku University Library(Kyoto, Japan).

vi For example, Jeong Yak-yong(1762-1836), the great synthesizer of the "Practical Learning" movement in Korea's neo-confucian thought, wrote some books of geography and geomancer regarding locations, geographical features, national defense, etc. with the Baekdudaegan as a center.

vii Jeonggan and Jeongmaek mean secondary and tertiary mountain ridges branching out of the Baekdudaegan. They form the watersheds of Korea.

viii The landscape analysis has been mainly focused on applied researches of natural components such as fauna and flora, water, geographical features, etc. and visual components of landscape such as artificial facilities. As of recent, biotic components are included to analyze the relationship among organisms and the effects of human activities on the natural environment. Landscape ecological approaches refer to attempts to analyze structures, functions and changes of landscape in the connection with natural, social and cultural changes. Land surfaces and use patterns conducted by human activities show the changes in landscape from the visual viewpoints as well as one aspect of people's land use from the social and cultural viewpoints. And thus landscape ecology has a purpose to examine the effects of human activities on ecosystem by analyzing structural and functional changes of land use.

ix In *Goryeo Segye*, a kind of history of the Goryeo Dynasty, the Baekdudaegan is understood as a center of national territory according to Monk Doseon's theory of geomancy.

x This theory is connected with Pungsujiri(theory of divination based on topography) as a folk belief, representing people's hope that they could be blessed with spirit of land.

xi Since the geographical range of the Baekdudaegan has not been defined, we present here the previous survey results of the Baekdudaegan. Most of previous researches were conducted along the ridgelines around the Baekdudaegan.

xii Sangju in Gyeongbuk, and Taeback and Mungyeong in Gangwon

xiii Taeback, Samcheok, Donghae, Gangneung, Sokcho, Yeongwol, Jeongseon, Pyeongchang, Hongcheon, Yangyang, Inje, and Goseong in Gangwon, Chungju, Jecheon, Yeongdong, Boeun, Goesan, and Danyang in Chungbuk, Gimcheon, Sangju, Mungyeong, Yeongju, Bonghwa, and

Yecheon in Geyongbuk, Hadong, Sancheong, Hamyang, and Geochang in Gyeongnam, Namwon, Jangsu, and Muju in Jeonbuk, and Gurye in Jeonnam

xiv Since the geographical range of the Baekdudaegan has not been defined, we examine here facilities located along the ridgelines around the Baekdudaegan.

xv Mt. Jiri, Mt. Deokyu, Mt. Sokri, Mt. Wolak, Mr. Sobaek, Mt. Odae and Mt. Seorak as national parks and Mungyeonsaejae and Mt. Taebaek as provincial parks

xvi Mt. Sobaek, Mt. Seorak, Mt. Geonbong, and Mt. Daeam and Mr. Daewoo

xvii A Bibliography Guide to the Baekdudaegan (1996), Current Situation and Conservation Policies of the Baekdudaegan (1997), A Survey on Forest Condition of the Baekdudaegan (1999), etc.

xviii The Forest Management Act (draft) is strengthening regulations related to forest development projects in the “major ridgelines” from Seorak Mountain to Jiri Mountain

xix “Righteous use” is the concept to respect nature’s own value and is similar with the concept of “sustainable development,” which is proposed as of recent. Please refer to *Deep Ecology* of Bill Devall and George Sessions (1985) for details.

xx The management scope of the Baekdudaegan is not identical with its geographical range, but it is desirable to establish the former on the basis of the latter. We have not defined geographical range of the Baekdudaegna academically or institutionally. In a broad sense, the Baekdudaegan includes the entire territory of the Korean peninsula, and in a narrow sense it means all the ridgelines of the Baekdudaegan. In order to decide its management scope in the landscape ecological perspectives, we need to analyze the structure and functions of the landscape of the Baekdudaegan. But we suffer difficulties in conducting the analysis due to insufficient information on the Baekdudaegan. Therefore, it is required to decide geographical range for the management of the Baekdudaegan in consideration of its significance and management goals.

xxi As the result of survey made with the degree of importance in 5 points, the importance of biological point of view is 4.24, the importance of geomancy point of view for 4.14, the historic and geographic point of view for 3.89, and the cultural point of view for 3.54. For more details, refer to the Ministry of Environment (2002).

8. REFERENCES

Agee, J.K. and Johnson, D.R. 1988. *Ecosystem management for parks and wilderness*. University of Washington Press, Seattle.

Bengston, D.N. 1993. The nature of value and the value of nature. In Society of American Foresters (Ed.), *Foresters together: Meeting tomorrow's challenges* (pp. 57~62.). Proceedings of the 1993 Society of American Foresters National Convention. Indianapolis, Indiana.

Butler, R.W. 1998. Sustainable: Looking Backwards in order to Progress? In C.M. Hall and A.L. Alan (Eds.). *Sustainable Tourism: A Geographical Perspective*. Addison Wesley Longman Limited, N.Y.

Catton, W.R., Jr, and Dunlap, R.E. 1980. A new ecological paradigm for post-exuberant sociology. *American Behavioral Scientist* 24:15~47

Choi, Y.-K. 1995. *The Nature of Forest Values toward Ecosystem Management.* Doctor Philosophy Theses, Department of Land Use and Landscape Planning, Agricultural University of Norway.

Choi, Y.-K. 2001. Environmental Carrying Capacity in Sustainable Tourism*.* In Kim, S.-I. (Ed.). *Sustainable Tourism.* Ilsin Press.

Choi, Y.-K. and Cho, K.-S. 2002. *Foreign Cases of Natural Environment Management Policies*. Korea Research Institute for Human Settlements.

Cole, D.N. 1982. *Wilderness Campsite Impact: Effect of Amount of Use*. USDA FS INT-284.

Creighton, J.L., and Chalmers, J.A. 1983. Integrating planning and assessment through public involvement. In G.A. Daneke, W.G. Margot and J.D. Priscoli (Eds.), *Public involvement and social impact assessment* (pp. 143~84). Westview Press, Boulder, Colorado.

Dale, V.H. and Haeuber, R.A. (Eds.) 2001. *Applying Ecological Principles to Land Management* Springer. New York. 346p.

Devall, B. and George S. 1985. *Deep Ecology*. Gibbs Smith Publisher, Layton, Utah. 267 p.

Dramstad, V.E., Olson, J.D. and Forman, R.T.T. 1996. *Landscape Ecology Principles in Landscape Architecture and Land-Use Planning*. Island Press, Washington.

Dunlap, R.E. and van Liere, K.D. 1978. The "New Environmental Paradigm". *Journal of Environmental Education* 9: 10~9.

Forman, R.T.T. and Godron, M. (1986). *Landscape Ecology*. John Wiley & Sons, New York

Korea Forest Service. 1997. *Survey on Current Status and Rational Conservation Policies of the Baekdudaegan*. The Korean Geographical Society (Korean)

Lee, C. 199*). Old Maps of Korea*. pp. 13~15.

Lee, D. 2001. *Landscape Ecology*. Seoul National University Press.

Lee, D. 2002. Ecological Philosophy and Conception in Korean Traditional Landscape. (unpublished). (Korean)

Lim, D.-S. 1999. Consideration of History and Geography of the Baekdudaegan. In *Proceedings of the Symposium on Concept Restoration and Management Directions of the Baekdudaegan*. Korea Research Institute for Human Settlements and Green Korea United.

Ministry of Environment. 2001. *A Study on Efficient Management Policies of the Baekdudaegan – Focusing on Establishment of Management Scope*.

Ministry of Environment. 2002. *A Study on Efficient Management Policies of the Baekdudaegan – Focusing on Establishment of Management Policies*.

Naveh, Z. and Lieberman, A. 1993. *Landscape Ecology*. Springer-Verlag, New York.

Overbay, J.C. 1992. Ecosystem management. In *Proceedings of the National Workshop: Taking an Ecological Approach to Management* (pp. 3~15). WO-WSA-3, Washington, D. C. Salt Lake City, UT: USDA Forest Service.

Park, I. 2002*. Environmental Philosophy*. Midas Books.

Riedel, W. and Lange, H. 2001. *Landschaftsplanung*. Specktrum, Akad. Verl., Heidelberg, Berlin.

Shin, J.-H. 2002. *Process for Concept Establishment of the Baekdudaegan and its restoration directions*. (unpublished).

Twight, B.W. and Lyden, F.J. 1989. Workshop in Public Involvement: Do They Help Find Common Ground? *Natural Resource Journal* 15: 297-306

WCED 1987. *Our Common Future*. Oxford University Press, Oxford.

Western, D. and Pearl, M. 1989. *Conservation for the Twenty-First Century*. Oxford University Press, New York.

Yang, B. 2002. Traditional Conception of Geography. In *Summary of the 2002 Spring Seminar of the Korean Geographical Society* (pp. 1~6).

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CHAPTER 23

FOREST FRAGMENTATION IN THE LOWER REGION OF THE HAN RIVER BASIN, SOUTH KOREA FROM 1983 TO 1996

1. INTRODUCTION

Landscape change has been largely influenced by human activities, especially in recent days. Population growth and various development activities caused significant change in landcover. Furthermore, industrialization and urbanization have created man-made barriers such as roads and railroads, which fragment ecosystems, thereby threatening biological richness and diversity. Fragmentation is recognized as one of the major anthropogenic changes of landscape.

Fragmentation is defined as progressive division of large, comparatively homogeneous tracts of forest into a heterogeneous mixture of much smaller patches (Reed *et al.* 1996a, b). Consequences of fragmentation include habitat loss for some plant and animal species, habitat creation for others, decreased connectivity of the remaining vegetation, decreased patch size, increased distance between patches, and an increase in edge at the expense of interior habitat (Reed *et al.* 1996a).

Change of landscape structure including fragmentation began to draw attention in ecosystem management because it is recognized that the spatial arrangement of elements in a landcover mosaic controls the ecological process which operate within it (Haines-Young *et al.* 1996, Ruzicka *et al.* 1990, Forman 1990, Forman 1995). To achieve the management goals such as conservation of species or natural resources, accurate information characterizing landscape structure and its change is critical prerequisite.

However, at the level of landscape, it is very time-consuming and labor-intensive survey that spatially explicit and temporal databases are developed and managed on the basis of traditional technology. The dramatic expansion of spatial and temporal scales at which many environmental problems must be considered has presented another difficult quantitative challenge (Turner *et al.* 1991). Fortunately, some recent achievements in the field of landscape ecology offer an opportunity on this problem. As one of these achievements, many investigators have been trying to

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quantify and evaluate the landscape using landscape indices with RS (Remote Sensing) and GIS (Geographic Information System) technology (Haines-Young and Chopping 1996).

The major objectives of this study were to quantify forest fragmentation in the Han River Basin, which has been subject to urbanization and road construction during the past years, from 1983 to 1996.

2. STUDY AREA

The study represents Kyunggi Province area in the Han River Basin, South Korea due to availability of satellite images (Fig. 1). The study area that includes Seoul and its satellite cities, has been impacted by suburbanization and road construction during the last several decades.

Northern and eastern part of the area is dominated by forest and characterized by high elevation and steep slope. On the contrary, western and southern part is covered with urban and agricultural areas (Fig. 2). Seoul Metropolitan Area and its many satellite cities are located in the central part of the area. The area is divided into fifteen sub-watersheds.

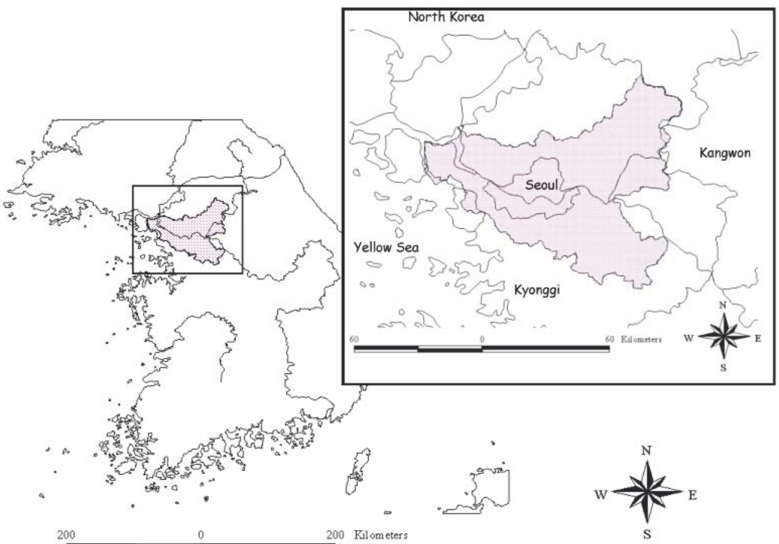

Figure 1. Study area

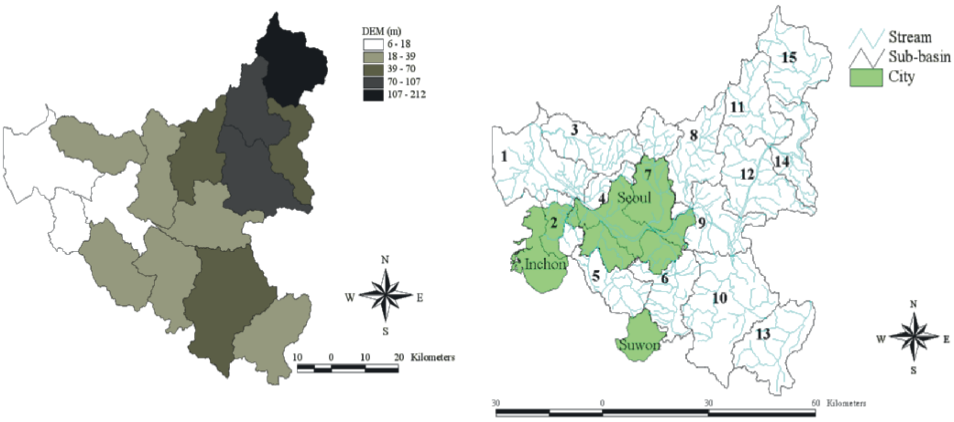

Figure 2. Elevation of study area (left) and sub-watersheds in the study area (right).

3. METHODS

3.1 Data processing

Four image sets, DEM (Digital Elevation Model) and topographic map sets were used to quantify the landcover change. Landsat TM image obtained in 1987, 1993, 1996 and Landsat MSS image in 1983 were used for classification of landcover. Topographic map sets were used for ground truth data. Resolutions of DEM, TM, and MSS image sets were 100m, 30m, and 80m, respectively, and the scale of topographic maps was 1:50,000. Geometric corrections of each satellite images were carried out on polynomial warping method.

Seven types of landcover are classified by a hybrid classification method (mixture of unsupervised and supervised classification) from satellite images of Landsat TM and MSS. Urban, suburban, bare soil (including non crop-covered agricultural area), field (including crop-covered agricultural area), forest, water, wetland are each landcover types. Because of scale effect from different resolution at TM (30m), MSS (80m), classification images derived from TM were aggregated in 80m grain size by majority rule. Majority rule was used because this rule preserves code system of landcover type in fine-scaled image and reported as valid method in scale-up effect of landscape indices by Benson *et al.* (1995). All the processes hereafter were conducted on the basis of 80m resolution.

Although roads are usually undetectable in a coarse resolution image, their effects on landscape structure are considerable. To minimize underestimation of the effect of roads on forest patches, road network digitized from 1:50,000 topographic maps was rasterized and overlaid on the landcover map.

All the catchment areas were computed from smoothed DEM. The overlay of catchment area and stream network were merged and assigned into 15 sub-basins, which were designated to minimize the difference in the area one another.

Four classification layers, 3 road network layers, and 15 sub-basin boundary layers were overlaid into final 60 landcover map sets that represent landcovers of 15 sub-basins in 1983, 1987, 1993, and 1996, respectively.

3.2 Landscape Indices

FRAGSTATS Version 2.0, which McGarigal and his co-workers have developed was used to calculate landscape indices. Many indices at the level of patch, class, and landscape were computed for each sub-basin from 1983 to 1996. Among these indices, only the class level indices were used to quantify the forest landscape. Definitions and descriptions of landscape indices used in this study were presented in Appendix.

Edge depth was fixed to 100m because of limitation of algorithm of the FRAGSTATS 2.0. According to Chen *et al.* (1996), edge effects in conifer forests in Pacific Northwest of North America continent were evident up to 137m. Vaillancourt (1995) reported the edge effects were evident to approximately 50m or more into the surrounding forest. In Korea, it was reported that depth of transient zone was observed up to 112m in Soraksan National Park, 220m or more in Pukhansan National Park (Suh 1996, Park 1995). Reed *et al.* (1996a, 1996b) defined edge depth from 50m to 100m in quantifying forest fragmentation on 10m resolution.

4. RESULTS AND DISCUSSION

4.1 Major landscape indices

To extract independent factors that explain the most change of each landscape without redundancy, factor analysis was conducted on each data sets using 32 indices. MSI, DLFD, MPFD, and AWMPFD were omitted before factoring the correlation matrix among 32 indices because the coefficient of variations of these four indices was less than 10%.

Factors were extracted by applying principal components analysis with orthogonal varimax rotation. The number of factors was determined as 4 groups based on the criteria that (1) the associated eigenvalue is greater than one, and (2) the power of cumulative explanation is greater than 80%, and (3) the slope of the plot of eigenvalue versus component number changes rapidly at that number of component.

The dimensions were interpreted by examining the factor pattern. The first axis was termed percentage of class area because it is positively correlated with area percent of landscape (C%LAND, and %LAND), and area-related indices (MCA1, MCA2, TCAI, MPS, LPI, and CA). The second axis was appeared to be a measure of patch dispersion because this axis was showed positive relationship with both the length of edge and the number of patches (LSI, ED, NCA, TE, and NP).

Table 1. Results of principal components factor analysis with varimax rotation.

	Factor1	Factor2	Factor3	Factor4	Factor5	
Eigenvalue	13.6976	6.4493	2.9819	1.3380	1.0020	
Cumulative	0.4892	0.7195	0.8260	0.8738	0.9096	
			Rotated Factor Pattern			*Communality*
C%LAND	0.9705	0.0474	-0.0109	0.0866	0.0963	0.9610
%LAND	0.9433	0.1945	-0.0303	0.0778	0.1363	0.9533
MCA2	0.9170	-0.2992	0.0919	0.0347	-0.1273	0.9563
MPS	0.9121	-0.2954	0.0138	-0.1102	0.1065	0.9428
MCA1	0.9082	-0.3222	0.0330	-0.1095	0.0604	0.9454
TCA	0.9051	0.2817	0.1233	0.1143	-0.0463	0.9291
TCAI	0.9012	0.1232	0.0611	0.2084	0.1470	0.8962
CASD2	0.8879	-0.3137	0.2484	-0.1026	-0.0556	0.9620
PSSD	0.8837	-0.3041	0.2147	-0.1947	0.0734	0.9628
CASD1	0.8820	-0.3242	0.2124	-0.1794	0.0322	0.9612
LPI	0.8582	-0.2897	0.3027	-0.1921	0.1488	0.9710
CA	0.8160	0.4648	0.1392	0.1117	-0.0562	0.9168
AWMSI	0.7236	0.0853	0.4088	-0.2363	0.4495	0.9559
PD	-0.7331	0.3745	0.1180	-0.1916	-0.3892	0.8797
NNSD	-0.8114	-0.4179	0.1468	0.1292	0.0381	0.8726
MNN	-0.8772	-0.3082	0.0751	-0.1031	-0.0923	0.8892
LSI	0.0257	0.9784	0.1283	-0.0011	-0.0956	0.9835
ED	-0.0742	0.9300	-0.0196	-0.0925	0.0635	0.8834
NCA	0.0290	0.9111	0.1368	0.0002	0.0055	0.8496
TE	0.0899	0.9091	0.1805	0.0325	-0.1781	0.8999
CAD	-0.1769	0.8640	-0.0904	-0.1255	0.3579	0.9298
NP	-0.4886	0.6270	0.2294	-0.0982	-0.4946	0.9386
CACV1	-0.0284	0.1698	0.9460	0.0049	-0.0385	0.9261
PSCV	0.4333	0.2234	0.8137	0.0363	0.1384	0.9202
CACV2	0.5945	0.1542	0.6405	-0.1471	0.3962	0.9660
MCAI	0.1153	0.0837	-0.7124	0.4096	0.3461	0.8153
IJI	-0.1199	0.0021	-0.2124	0.8479	-0.1188	0.7925
NNCV	0.1063	-0.4441	0.0955	0.5922	0.2006	0.6086
Sum	9.5933	4.1054	4.2837	0.8025	1.1043	25.4688
			Variance explained by each factor			
	13.0651	6.3531	3.1597	1.6405	1.2504	

The third axis was most correlated with patch area coefficient of variation (CACV1, CACV2, and PSCV), which describe patch size heterogeneity in a landscape. The fourth axis was most correlated with interspersion and juxtaposition (IJI). This is a measure to describe how a particular class is interspersed and juxtaposed with another classes in landscape (Table 1). After all, individual indices were selected to represent each factor on the basis of higher correlation with a given factor and a lower correlation with all others (Table 2).

Table 2. Representative indices for the 4 factors

Name of each factor	Indices	Name of indices
Percent area of landscape	C%LAND	Core area percent of landscape
Patch dispersion	LSI	Landscape shape index
Patch size heterogeneity	CACV1	Core area coefficient of variation
Interspersion and juxtaposition	IJI	Interspersion and juxtaposition index

4.2 General trend of forest fragmentation from 1983 to 1996

Simple summary statistics on 4 representative indices were presented in Table 3. These simple statistics were means and standard deviations based on 15 sub-basins for each observation year (1983, 1987, 1993, and 1996), respectively. C%LAND decreased by 9.02% from 1983 to 1996, that is, roughly 0.69% of forested areas per a year have been developed in every year. LSI increased by 0.6, CACV1 and IJI increased by 15 and 4.4% respectively. In general, forest patches changed into smaller and more irregular form, heterogeneity of sizes of forest patches within sub-basin increased, and variety of patch types around forest patches increased from 1983 to 1996.

Table 3. Simple summary statistics of 4 representative indices

Indices \ Year		83	87	93	96
C%LAND	*Mean*	38.24	35.36	31.64	29.22
	StdDev	24.24	22.21	22.74	20.61
LSI	*Mean*	17.68	17.52	17.33	18.28
	StdDev	5.29	5.05	5.06	4.86
CACV1	*Mean*	958.22	1076.34	1112.83	972.87
	StdDev	189.56	266.28	299.91	224.02
IJI	*Mean*	33.48	41.94	38.45	37.92
	StdDev	7.64	7.32	6.29	5.63

Table 4. Change of 4 representative indices in each sub-watersheds from 19883 to 1996

	C%LAND				LSI			
Wshd \ Year	83	87	93	96	83	87	93	96
W01	8.25	5.76	3.08	3.65	20.98	16.28	15.34	17.72
W02	6.44	4.6	2.14	2.69	8.92	7.21	7.22	7.88
W03	27.72	22.41	16.08	16.26	22.19	21.82	20.3	22.5
W04	13.71	13.75	10.64	8.9	14.36	14.35	13.55	13.65
W05	18.62	22.23	15.86	13.8	19.11	17.27	16.19	17.75
W06	26.87	31.99	26.62	23.14	23.07	20.43	18.99	18.77
W07	23.43	24.19	17.43	16.78	17.3	16.8	16.94	17.88
W08	52.11	45.05	40.08	37.39	18.52	21.89	21.14	19.96
W09	36.42	34.17	31.56	29.81	18.5	18.53	18.37	17.28
W10	51.22	46.94	42.13	37.72	28.39	29.59	30.63	30.63
W11	68.24	61.72	60.22	56.95	13.37	16.09	16.04	16.91
W12	70.37	64.12	60.08	56.73	14.91	17.38	18.55	18.85
W13	25.55	20.25	17.95	17.61	22.32	17.92	18.84	22.09
W14	65.51	56.52	57.46	52.2	13.09	16.08	15.3	16.62
W15	79.07	76.75	73.31	64.6	10.16	11.11	12.5	15.77

	CACV1				IJI			
Wshd \ Year	83	87	93	96	83	87	93	96
W01	950.87	1303.37	1251.46	927.73	27.27	34.32	32.28	32.57
W02	589.31	621.32	727.94	607.62	30	39.21	38.1	40.3
W03	852.27	1087.3	1157.77	1038.77	29.22	34.26	32.56	35.88
W04	1199.06	1476.26	1700.47	1332.43	44.04	49.25	42.73	42.84
W05	953.74	1113.36	1184.35	1023.67	32.46	45.34	34.13	37.74
W06	1014.04	941.15	925.02	902.73	31.11	47.33	43.86	41.95
W07	782.44	924.84	935.2	891.36	39.15	45.9	32.82	38.45
W08	1219.29	1425.18	1440.84	1210.29	27.48	37.76	35.35	37.49
W09	1062.84	1251.78	1249.03	1149.41	40.44	51.94	48.14	44.96
W10	1025.44	1224.88	1291.01	1184.18	30.04	43.47	40.75	38.63
W11	981.05	1149.7	1142.48	977.39	26.09	30.38	33.7	31.9
W12	879.05	937.37	946.29	842.74	35.3	48.68	40.02	39.68
W13	1205.37	869.41	887.58	917.5	23.85	39.52	41.72	37.83
W14	630.61	567.68	498.73	475.13	52.24	51.11	51.08	45.4
W15	1027.86	1251.47	1354.25	1112.17	33.47	30.7	29.56	23.13

4.3 Temporal aspect of fragmentation

Temporal changes of four indices are presented in Figure 3. In the first stage (from 1983 to 1987), as dissection and isolation by road construction occurred across the whole area, core area percent of landscape reduced. These small islands separated from irregular shaped large patch contributed to decrease in complexity of

patch shape and to increase in patch size heterogeneity. Interspersion and juxtaposition increased with these processes. First stage can be summarized as road construction and partitioning of many small islands of forest. From 1987 to 1993, these trends began to change with intensive urbanization. Urban expansion around road network and its intersection in lowland produced small islands around larger one. Intensive urbanization also decreased mainly areas of these small islands and made landcover pattern around these island forest patches intensive and homogeneous. Consequently, although forested area, its shape, and patch size heterogeneity showed the same trends as in previous stage, interspersion and juxtaposition began to decrease because of predominance of urban landuse around the islands of forest patch (Figure 3).

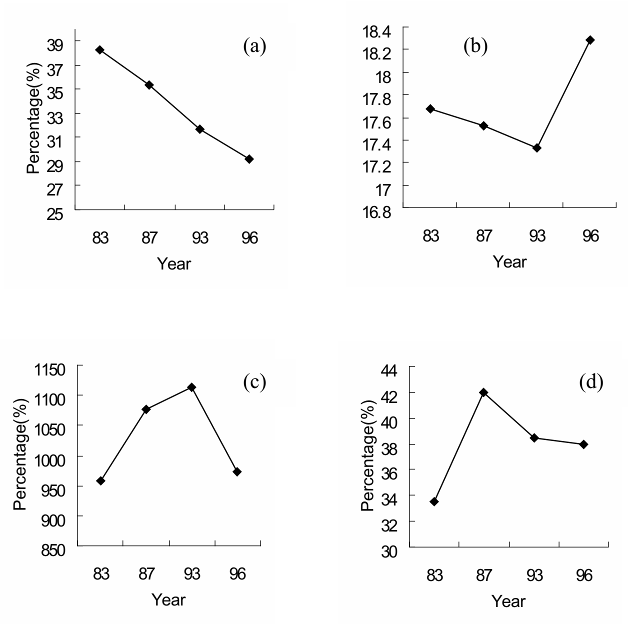

Figure 3. Changes of representative indices in each time stage: (a) core area percent of landscape, (b) landscape shape index, (c) patch core area coefficient of variation, and (d) interspersion and juxtaposition index

At the last stage, C%LAND and CACV1 decreased, IJI was almost unchanged, and LSI increased (Fig. 4). This means that many small-scale developments around the boundary of large forest patch, rather than a few big scale modifications in interior area of forests, were a main factor of landcover change

These changes in landcover pattern can be explained by two factors. One is, as it was reported by some studies such as Park (1997), and Cho (1996), commercial and residential developments in Quasi-Farm Zone introduced in the National Landuse

Plan in 1993 through reforming the National Land-Use Management Law in order to provide sufficient land supply. In this case, IJI slightly increased with increasing LSI. The other factor is developments along the contour line. In this case, IJI decreased with increasing LSI. Change by commercial and residential developments was outstanding in sub-basin 9, and change by agricultural development was shown well in sub-basin 10 and 13.

4.4 Spatial pattern of forest fragmentation

Distribution of forested area tends to concentrate in upland area. Figure 4a represents core area percent of landscape, which shows very similar tendency of DEM (Fig. 2) and slope. This analogy means that human landuse pattern has been influenced by the natural conditions such as elevation and slop.

Core area percent of landscape varied from 5% (watershed 1) to 73% (watershed 15). The most forested area was Mt. Myungji, lying in Gapyung-Gun. On the contrary, the most fragmented sub-watershed includes the City of Kimpo and Ilsan, which were newly developed as satellite cities of Seoul Metropolitan Area. These areas also include extensive rice paddy field.

In agricultural landscape, which is mainly located in the south-eastern, western, and north-western areas of the study site, landscape shape index was relatively high (Fig. 4b). Especially, sub-basin 3, 8, and 10 that have moderate values of elevation and slope show the highest LSI. In these areas, as continuous conversion of landcover was made up along contour lines, very irregular shrinkage occurred across the wide range of a landscape. However, sub-basin 2 that includes Kimpo plain showed very low value of LSI, because large urban area and intensive rice paddy fields made shape of forest landscape more geometric.

Spatial distribution of patch size heterogeneity is shown in Figure 4c. Patch size heterogeneity was high in the sub-basins that include intensive urban area and large forested area at the same time. Sub-basin 15, however, showed relatively high value of CACV1 because it does not have moderate size forests and only has two very large forests with very small forests that consist of one or two pixels. Sub-basin 2 and 14 showed the lowest values, but these 2 sub-basins have totally different characteristics. Sub-basin 2 consists of a number of very small patches (C%LAND 3.97%), on the other hand, sub-basin 14 includes a number of moderate size patches (C%LAND 57.92%). Sub-basin 2 is the most fragmented, but sub-basin 14 is not.

Interspersion and juxtaposition index was relatively high along the Han River (Fig. 4 d). In this area, forest patches often face directly with various types of landcover, because landuse pattern of this area is mixed and confused. These areas also include Quasi-Farm Zone introduced in the National Landuse Plan at 1993. Frequent modification for the commercial or residential purpose around Quasi-Farm Zone and urban area led to perforation in forest landscape. As the result, interspersion and juxtaposition was high in this area.

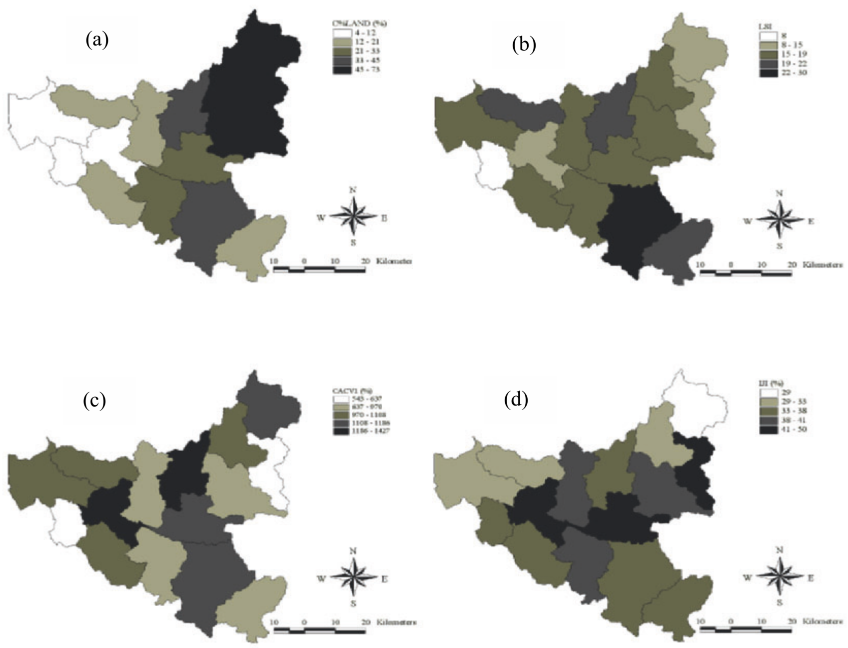

Figure 4. Spatial distribute on of indices (a: C%LAND, b: LSI, c: CACV1, d: IJI)

5. CONCLUSIONS

During the period of time, core area percent of landscape decreased by 9.02% and landscape shape index, patch core area coefficient of variation, and interspersion and juxtaposition index increased by 0.60, 14.65, and 4.44%, respectively. The results indicates that forest patches changed in smaller and more irregular forms, that heterogeneity of forest patch size within sub-watershed increased, and that patch shapes were varied from 1983 to 1996.

Dissection by road construction was a main factor governing forest fragmentation from 1983 to 1987, while urban expansion played a key part from 1987 to 1993. Perforation and shrinkage by unplanned frequent modification centering on Quasi-Farm Zone were important process from 1993 to 1996. At spatial scale, urbanization with dissection in lowlands, shrinkage and perforation in agricultural landscape, and perforation along the Han River were differentiated.

The study also suggests that landscape indices can offer many opportunities to analyze change of land uses if it is used at an appropriate scale. Landscape indices can be used to quantify and summarize broad landscape, and compare and evaluate landscape structures at various spatial and temporal scales.

6. REFERENCES

Benson, B.J. and Mackenzie, K.D. 1995. Effects of sensor spatial resolution on landscape structure parameters. *Landscape Ecology* 10: 113-120.

Chen, J., Franklin, J.F. and Lowe, J.S. 1996. Comparison of abiotic and structurally defined patch patterns in a hypothetical forest landscape. *Conservation Biology* 10: 854-862.

Cho, D. 1996. A study on the landuse characteristics along the northern-Han River of Kyonggi Province. Master's Thesis. Graduate School of Environmental Studies, Seoul National University, Korea.

Forman, R.T.T. 1990. Ecological sustainable landscapes: the role of spatial configuration. In I.S. Zonneveld and R.T.T. Forman (Eds.), *Changing landscapes: an ecological perspective* (pp. 261-278). Springer-Verlag, New York.

Forman, R.T.T. 1995. *Land mosaics: The ecology of landscapes and regions*. Cambridge University Press, Cambridge.

Haines-Young, R. and Chopping, M. 1996. Quantifying landscape structure: a review of landscape indices and their application to forested landscapes. *Progress in Physical Geography* 20: 418-445.

McGarigal, K. and Marks. B.J. 1994. FRAGSTATS: a spatial pattern analysis program for quantifying landscape structure v2.0 (unpublished computer program, user manual and guide), Oregon State University, Corvallis.

Park, C. 1995. A study on the evaluation method of urban open spaces of Seoul with remote sensing: Detection of the ecotone of the Mt. Pukhansan National Park. *Journal of the Korean Society of Remote Sensing* 11: 71-81.

Park, M. 1997. A study on the land use characteristics of quasi-farm zone in case of Seoul metropolitan area. Master's Thesis. Graduate School of Environmental Studies, Seoul National University, Korea.

Reed, R.A., Johnson-Barnard J. and Baker. W.L. 1996a. Fragmentation of a forested Rocky Mountain landscape, 1950-1993. *Biological Conservation* 75: 267-277.

Reed, R.A., Johnson-Barnard J. and Baker. W.L. 1996b. Contribution of roads to forest fragmentation in the Rocky Mountains. *Conservation Biology* 10: 1098-1106.

Ritters, K.H., O'Neill, R.V., Hunsacker, C.T. , Wickham, J.D., Yankee, D.H. Timmins, S.P., Jones K.B. and Jackson, B.L. 1995. A factor analysis of landscape pattern and structure metrics. *Landscape Ecology* 10: 23-39.

Ruzicka, M., and Miklos, L. 1990. Basic premises and methods in landscape ecological planning and optimization. In I.S. Zonneveld and R.T.T. Forman (Eds.), *Changing landscapes: an ecological perspective* (pp. 233-260). Springer-Verlag, New York.

Steven, M.B. and Brekert, A.L. (1991) A spatial-temporal model of nitrogen dynamics in a deciduous forest watershed. In M.G. Turner and R.H. Gardner (Eds.), *Quantitative methods in landscape ecology* (pp. 379-398). Springer-Verlag, New York.

Suh, K-J. 1996. A study on the analysis of the impacts of human activity on Soraksan National Park vegetation using GIS and remote sensing technologies. Master's Thesis. Graduate School of Environmental Studies, Seoul National University, Korea.

Swanson, F.J., Neilson, R.P. and Grant, G.E. 1992. Some emerging issues in watershed management: Landscape patterns, species conservation, and climate change. In R.J. Naiman (Ed.), *Watershed Management: Balancing Sustainability and Environmental Change* (pp. 307-323). Springer-Verlag, New York.

Turner M.G. and Gardner, R.H. 1991. Quantitative methods in landscape ecology: An Introduction. In M. G. Turner and R.H. Gardner (Eds.), *Quantitative methods in landscape ecology* (pp. 3-14). Springer-Verlagm New York.

Vaillancourt, D.A. 1995. Structural and microclimatic edge effects associated with clearcutting in a Rocky Mountain forest. Master's Thesis. Department of Geography and Recreation, University of Wyoming Laramie, WY, USA.

Wickham, J. D., O'Neill, R.V., Ritters, J.H., Wade, T.G. and Jones, K.V. 1997. Sensitivity of selected landscape pattern metrics to land-cover misclassification and differences in land-cover composition. *Photogrammetric Engineering & Remote Sensing* 63: 397-402.

7. APPENDIX

Abbreviations	*Names*	*Description*
CA	Class Area	Sum of the areas of all patches of the corresponding patch type
%LAND	Percent of Landscape	Percentage of the landscape comprised of the corresponding patch type
LPI	Largest Patch Index	Percentage of the landscape comprised by the largest patch
NP	Number of Patches	Number of patches of the corresponding patch type
PD	Patch Density	Number of patches of the corresponding patch type per 100 hectares
MPS	Mean Patch Size	Mean patch size in hectare
PSSD	Patch Size Standard Deviation	Variability in patch size
PSCV	Patch Size Coefficient of Variation	Variability in patch size relative to the mean patch size
TE	Total Edge	Sum of the lengths of all edge segments involving the corresponding patch type
ED	Edge Density	Sum of the lengths of all edge segments involving the corresponding patch type per one hectare
LSI	Landscape Shape Index	LSI increases as landscape shape becomes more irregular and/or as the length of edge within the landscape of the corresponding patch type increases.
MSI	Mean Shape Index	MSI increases as the patch shapes become more irregular.
AWMSI	Area-Weighted Mean Shape Index	Average shape index of patches of the corresponding patch type, weighted by patch area so that larger patches weigh more than smaller patches
DLFD	Double Log Fractal Dimension	Fractal dimension approaches 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.
MPFD	Mean Patch Fractal Dimension	
AWMPFD	Area-Weighted Mean Patch Fractal Dimension	
C%LAND	Core Area Percent of Landscape	Percentage the landscape comprised of core area of the corresponding patch type
TCA	Total Core Area	Sum of the core areas of each patch of the corresponding patch type
NCA	Number of Core Areas	number of disjunct core areas contained within the landscape
CAD	Core Area Density	sum of number of disjunct core areas contained within each patch of the corresponding patch type per 100 hectares
MCA1	Mean Core Area Per Patch	average core area per patch
CASD1	Patch Core Area Standard Deviation	variation in core area among patches
CACV1	Patch Core Area Coefficient of Variation	variability in core area relative to the mean core area
MCA2	Mean Area Per Disjunct Core	average disjunct core area per patch
CASD2	Disjunct Core Area Standard Deviation	variation in disjunct core area among patches
CACV2	Disjunct Core Area Coefficient of Variation	variability in disjunct core area relative to the mean core area
TCAI	Total Core Area Index	percentage of a patch type in the landscape that is core area
MCAI	Mean Core Area Index	average percentage of a patch of the corresponding patch type in the landscape that is core area
MNN	Mean Nearest-Neighbour Distance	Mean nearest-neighbour distance based on nearest edge-to-edge distance, for each patch of the corresponding patch type
NNSD	Nearest-Neighbour Standard Deviation	Variation in nearest-neighbour distance
NNCV	Nearest-Neighbour Coefficient of Variation	variability in nearest neighbour distance relative to the mean nearest neighbour distance
IJI	Interspersion and Juxtaposition Index	observed interspersion over the maximum possible interspersion for the given number of patch types

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PART IV

EPILOGUE

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CHAPTER 24

SUMMARY OF THE VIII SEOUL INTECOL CONGRESS AND SUBSEQUENT PROGRESSES IN ECOLOGY IN KOREA AS WELL AS IN EAST ASIA

1. INTRODUCTION

Since the first INTECOL Congress was held in The Hague, The Netherlands, in 1974 with the theme, "*Structure, Functions and Management of Ecosystems*," subsequent Congresses have followed: 2nd INTECOL- Jerusalem (Israel) 1978, "*The Future of Ecology*"; 3rd INTECOL in Warsaw (Poland) was cancelled for political reasons; 4th INTECOL- Syracuse (U.S.A.) 1986, "*Global Connections in Ecological Theory and Practice*"; 5th INTECOL- Yokohama (Japan) 1990, "*Development of Ecological Perspectives for the 21st Century*"; 6th INTECOL- Manchester (U.K.) 1994, "*Progress to Meet the Challenge of Environmental Change*"; 7th INTECOL- Florence (Italy) 1998, "*New Tasks for Ecologists after Rio 1992*." At the beginning of the 21st Century, ecological issues have never been more important both at a global scale and at a national level. The International Congresses of Ecology provided important fora to learn more about these issues, to discuss recent advances in ecological science, and to highlight deficiencies in the knowledge, which we urgently need to address. After the VII Congress in Florence, Italy, 1998, the VIII Congress in Seoul, Korea, provided an important opportunity for ecologists to continue the advancement of the science of ecology, and to learn at first hand of the many pressing problems that need to be addressed. The motto of the congress was "*Ecology in a Changing World*." This paper was prepared to summarize the activities and to report the progress and achievements of the Congress.

2. THE BACKGROUND OF THE CONGRESS

The VIII INTECOL Congress was co-hosted by the International Association for Ecology (INTECOL) and the Ecological Society of Korea (ESK) and organized by the Local Organizing Committee (LOC). The Ministry of Environment of the Republic of Korea, Kookmin Bank, KT Ltd., Asiana Airlines, Yuhan-Kimberly Ltd.

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and Pulmuwon Ltd., were the Gold-sponsors of the Congress. While the Korea Research Foundation, Seoul Metropolitan Government, and the Korea Science and Engineering Foundation, the Korean Federation of Science and Technology Societies, the Korean Association of Biological Sciences, Korean Forestry Society, and Korean Institute of Landscape Architecture were the major domestic sponsors, the Ecological Society of Japan, Chinese Academy of Sciences, the Ecological Society of America, the British Ecological Society, International Long-Term Ecological Research Network, and the International Association for Landscape Ecology were the major international sponsors.

The Ecological Society of Korea decided to host the VIII INTECOL Congress in October 2000. After the decision was made, the first Joint Meeting between INTECOL and the delegates of the ESK was held in Florence, Italy, December 2000. During the meeting, the specifics for the VIII Congress, including the date, venue, motto, the publication of circulars, fund raising, schedule of the Congress, etc., were discussed. While the Korean delegates offered to discuss the proposal with the ESK and to communicate their recommendations and concerns to INTECOL, all the participants agreed to move ahead with the plans for the next Congress. During the Congress, the specifics of the 1st Circular, such items as General Information, Scientific Program, Excursions, Call for Symposia and Papers, and other important issues for the Congress were discussed. During the period of December 14-15, 2001, the 2nd Joint Meeting between the INTECOL Promoting Committee and the LOC was held in the COEX Convention Center, Seoul, Korea. At the meeting, after the progress reports of the INTECOL Board and the LOC were presented, details of the Congress, such as an overview of the schedule, plenary and special lectures, finance and budget, publicity, venue, promotion of ecological societies at the national or regional levels, publications, public relations, the social program of the INTECOL Congress, student prizes, tour programs, website, exhibition, accommodation, cooperation between the INTECOL and LOC, etc., were discussed. The outcomes of the event were significant in the sense that it reaffirmed the prospects of success for the congress. The 3rd Joint Meeting between INTECOL Promoting Committee and LOC was held during the period of April 27-28, 2002 at COEX Convention Center, Seoul, Korea. At the Meeting, all the details for hosting the Congress were discussed and specific problems were addressed. These Joint Meetings provided the Local Organizing Committee with the platform for the successful launch of the Congress. In addition to the International Promoting Committee and LOC, Advisory Board, Technical Board, and Sub-Committees were organized and more than 20 sub-committees were formulated under the LOC. For the Congress, weekly or biweekly meetings of LOC were held more than 50 times before the opening of the Congress.

3. MAJOR ACTIVITIES

The VIII International Congress of Ecology in Seoul, a worldwide academic festival for the ecologists and environmentalists, provided an opportunity for enhancing research capabilities of domestic scientists in the field as well as

promoting ecological research in the world at large. In total, 1,623 participants from 55 countries registered and additional ca. 2,000 people of the general public attended the Congress. The Congress program book listed 1,267 papers, including both oral and poster presentations. In Figure 1, the number of registrants for the Congress is shown by country.

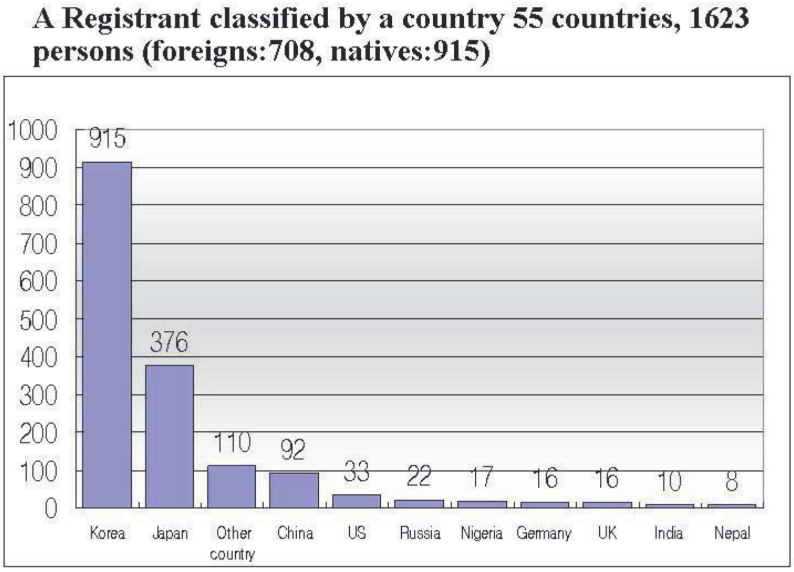

Figure 1. The number of registrants for the Congress by country

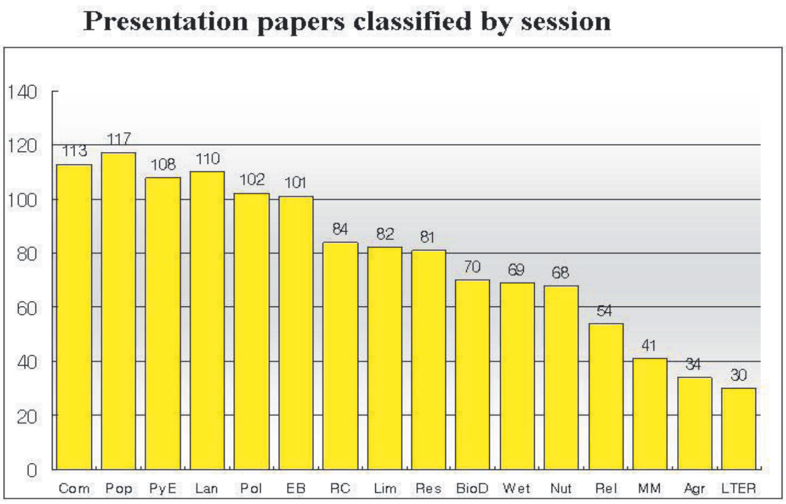

Figure 2. The number of papers presented at the Congress by category of ecology

In Figure 2, the number of papers presented at the Congress is shown by category of ecology, where Com: Community Ecology, Pop: Population Ecology, Pye: Physiological Ecology, Lan: Landscape Ecology, Pol: Pollution Ecology, EB: Evolutionary and Behavior Ecology, GC: Global Climate Change, Lim: Limnology, Res: Restoration Ecology, BioD: Biodiversity, Wet: Wetland Ecology, Nut: System Ecology, Rel: Plant-Animal relationship, MM: Molecular Ecology and Microbial Ecology, Agr: Agroecology, LTER: Long-Tern Ecological Research, respectively.

To illustrate the major themes, morning and evening plenary sessions were given including 11 keynote speeches and 10 public lectures. In addition, 70 invited symposia, 26 contributed paper and workshop sessions and 23 poster sessions were given.

3.1 Keynote speeches

The Plenary Sessions were organized with the authors and titles suggested as follows:

- Peter Grant, Princeton University, USA - *Adaptive radiation in Darwin's finches*
- Lech Ryszkowski, Poland - *Agricultural landscape management*
- Hen-Biau King, Taiwan - *Development of international long-term ecological research (LTER) network with special emphasis on East Asia-Pacific regional LTER research*
- Helmut Lieth, University of Osnabruk, Germany - *Biodiversity, energy and information flow in ecosystems: A contribution to ecological theory*
- John Grace, University of Edinburgh, UK - *Terrestrial carbon sink: Here today and gone tomorrow*
- Fakhri Bazzaz, Harvard University, USA - *Carbon dioxide and vegetation: How much can the Earth take?*
- Joel Cohen, Rockefeller University, USA - *Food web, body size and species abundance in descriptions of ecological communities*
- Akira Miyawaki, Japanese Center for International Study in Ecology, Japan - *Ecological restoration and creation of living environments: Principles and applications*
- Wenhwa Li, China - *Development and perspectives of ecology in China*
- Joon-Ho Kim, Seoul National University, Korea - *One hundred years of ecology in Korea*
- Eugene Turner, Louisiana State University, USA - *Water quality and land use in the World's large rivers*

3.2 Public lectures

- Rosemary Grant, Princeton University, USA - *A Life on the Galapagos Islands*

- In-Kyu Lee, Seoul National University, Korea - *Biodiversity in Korea: Past, present and future*
- Kook Hyun Moon, Yuhan-Kimberly Ltd., Korea - *Forest Vision and CSO's Roles*
- Bryan Norton, Georgia Institute of Technology, USA - *Measuring sustainability: Toward a pluralist and integrative framework for evaluating anthropogenic environmental impacts*
- Daniel Perlman, Brandeis University, USA - *A plea for small reserves: Their role in nurturing tomorrow's conservationists*
- Kyung-Ri Park, Author of a Korea Novel "Land" - *Literature and ecology*
- Robert Ayres, INSEAD, France - *Ecology vs. Economics: How helpful is the analogy?*
- Wolfgang Haber, Technical University of Munich, Germany - *Ethics and morality in the sciences: Views and experiences of an Ecologist*
- Yoshitaka Tsubaki, National Institute for Environmental Studies, Japan - *A message from a dragonfly: A condition-dependent signal and a status-dependent response*
- Jae Chun Choe, Seoul National University, Korea - *A new ethics for the brave new world: An evolutionary view*

3.3 Invited Symposia

Table 1. List of invited symposia and organizers

Symposia	*Organizers*
Complex ecosystem approaches to study human-environmental interactions	Felix Muller & Bai Lian Li
Plants in environmental change	Fakhri A. Bazzaz & Tadaki Hirose
Spatio-temporal patterns of populations	Yoh Iwasa & Yoohang Song
Ecological dynamics of urban and rural landscapes	Yukihiro Morimoto, Sun-Kee Hong & Nobukazu Nakagoshi
Biological interactions and proximate cues to understand tropical flowering	Tanaka Kenta & Tomoaki Ichie
Ecology in beech and oak forests the basic theory and response to global changes	Kazue Fujiwara, Gian-Reto Walther & Elgene O. Box
Partitioning carbon fluxes within forest stands beneath flux tower	Kaneyuki Nakane & Henry L. Gholz
New aspects for rice differentiation and ecology with an aid of genome database	Ryuji Ishikawa & Nam Jin Chung
Assessment, management, conservation and use of crop diversity in agroecosystems in a changing world	Devra I. Jarvis & V. Ramanatha Rao
Legacy and action from landscape ecology in a changing world	Sun-Kee Hong & Almo Farina
Fire and ecological responses	Yeonsook Choung, Takao Kikuchi & Satoshi Tsuda
Ecotoxicological investigation: Its potential and limitation in environmental research	Jinhee Choi & Man Bock Gu
Production and conservation of grassland ecosystems in northwest China	Masae Shiyomi

Ecological Network	Yeong Kook Choi
Ecology of Satoyama; rural landscape of East Asia	Daisuke Sakuma
Ecological techniques of conservation and management for mangrove ecosystems	Takehisa Nakamura & Kazuhiko Ogino
Spread of introduced tree pest organism pinewood nematode	Katsumi Togashi, Yeong-Jin Chung & Eiichi Shibata
Landscape ecological management in watersheds and biodiversity	Nobukazu Nakagoshi
Mathematical view of community and ecosystem processes	Toshiyuki Namba & Tae-Soo Chon
Arid and semi-arid lands in a changing world	Kamal H. Batanouny
Remediation of metal pollution in the environment	M.N.V. Prasad
Eco-polis planning and management in China	Rusong Wang
Recent findings in global biogeochemical cycles	Hojeong Kang & Chris Freeman
Biosphere-atmosphere interactions	Walter C. Oechel & Joon Kim
Microbial Ecology	Geon-Hyoung Lee & Tae-Seok Ahn
Gas emissions from buffer zones in agricultural landscape	Lech Ryszkowski & Ulo Mander
Plant-animal interactions in grassland ecosystems	Masae Shiyomi & Masahiko Hirata
Biological richness of tidal flats in West Sea, Korea and Ariake Sea, Japan and their crisis by human impact	Masanori Sato, Jong-Geel Je & Chul-Hwan Koh
Threats, protection, and restoration of freshwater ecosystems	Takayoshi Tsuchiya & Wolfgang Grosse
Urban forest and construction of ecological city in East Asia	Youngchang Song
Biodiversity and resources partitioning of freshwater fishes in Korea	Yong-Mok Son & Ik Soo Kim
Ecology of Asian mammals	Masatoshi Yasuda & Sang Hoon Han
Long-Term Ecological Research (LTER) and Sustainable management of Ecosystems	Hen-Biau King & Eun-Shik Kim
Theories in evolutionary and behavioral ecology	Masakazu Shimasa & Mun Il Ryoo
Priorities for arresting environmental degradation and biodiversity losses	R. S. Ambasht
Role of landscape ecology for restoring ecosystems in changing Asia	Xiao Duning, Nobukazu Nakagoshi, Xiuzhen Li & Sun-Kee Hong
Plant population ecology spatial dynamics and demographic genetics	Hiroshi Kudoh, Shoichi Kawano & Byeong Mee Min
Conservation and management of grassland biodiversity in East Asia	Osamu Imura and Kun Shi
Heliogeophysical influence on biosphere and climate	Oleg I. Shumilov
Ecological and evolutionary uncertainties in populations and communities	Kei-Ichi Tainaka, Nariyuki Nakagiri & Jin Yoshimura
Desertification and dust storm in a changing world	Tao Wang
Ecology of deciduous broad-leaved forests of temperate zone in East Asia	Keiichi Ihno
Theories and models for ecological restoration practice	Young D. Choi
Modeling ecosystem on very different space-time scales	Alcia Palacios-Oueta & Jerry Olson
Wetland conservation ecology associated with rice cultivation in Asia	Kazumasa Hidaka, Michiko Shimoda & Young Son Cho
Allelopathy and allelochemicals in sustainable agriculture and forestry	Azim U. Mallik & Young-Goo Park
Ecological engineering in Eastern Asian Rivers	Mahito Kamada, Hyoseop Woo & Yasuhiro Takemon
Aquatic food web and matter cycling	Shin-Ichi Nakano & Soon-Jin Hwang

Evolutionary ecology of sexual reproduction and related phenomena	Jin Yoshimura, Nariyuki Nakagiri & Kei-Ichi Tainaka
Leaf phenology, physiological ecology, and geographical distribution of evergreen and deciduous trees	Kihachiro Kikuzawa
Biomass and nutrient cycling of natural forests in Korea	Yowhan Son
Urbanization and spatiotemporal changes in ecosystems	Tae Ho Ro
Role of tundra ecosystems in global environmental change	Hiroshi Kanda
Molecular ecology and genetic diversity	Atsushi Higashitani & Kwan-Sam Choi
Application of ecological vegetational restoration for landscape planning and management	Kyoo-Seock Lee
Vitality and health of coniferous forests in East Asia under global environmental change	Takayoshi Koike, Hyun-O Jin & Yo Hwan Son
Land-use and ecological integrity	Yeong Guk Choi
Perspective of geoinformatics ecosystem studies integration	Hiromichi Fukui & Myung Hee Jo
The structure and function of tidal flats ecosystem	Byung-Sun Ihm & Seiichi Nohara
Vegetation mapping - How can vegetation mapping contribute to environmental conservation and planning locally and globally? The theory and utilization	Franco Pedrotti
Nature, culture, and eco-philosophy	Dowon Lee & Sun-Kee Hong
Studies on traditional medicinal plants in Korea	Youn-Chul Kim & Young-Gab Yun
Ecological evaluation and eco-corridor planning for the Mankyung River in South Korea	Myung Woo Lee & Bong-Seop Kil
Broad-based comparative reality of vegetation distribution in East Asia	Akira Miyawaki
Environment and Policy	Hoi Seong Jeong

3.4 Social Programs

During the Congress a social program was organized including the Welcome Reception and Korean Night, The Congress Banquet, Congress tours for participants and accompanying persons, and Exhibitions. During the Congress, the Internet Homepage with the address, www.seoulintecol.org, served as a base center for interactions and for information exchange.

3.5 Official Publications

In addition to Program, Proceedings, and Plenary Lecturers and Public Lectures books, a couple of new books, "*Ecology of Korea*" and "*Beautiful Wildflowers in Korea*" were published and distributed to foreign participants.

- Do-Soon Cho, Eun Ju Lee, Gea-Jae Joo, Kang-Hyun Cho, Sei-Woong Choi, Sun-Kee Hong, Jae C. Choe, Eun-Shik Kim, Byung-Sun Ihm and Bong-Seop Kil. *Proceedings of the VIII INTECOL International Congress of Ecology*. 2002. The Organizing Committee of 8th INTECOL Congress.
- Eun Ju Lee, Young D. Choi, Kang-Hyun Cho, Do-Soon Cho, Gea-Jae Joo, Sei-Woong Choi, Sun-Kee Hong, Jae C. Choe, Eun-Shik Kim, Byung-Sun Ihm and Bong-Seop Kil. *Program of the VIII INTECOL International Congress of Ecology*. 2002. The Organizing Committee of 8th INTECOL Congress.

- Young D. Choi, Do-Soon Cho, Eun Ju Lee, Kang-Hyun Cho, Gea-Jae Joo, Sei-Woong Choi, Sun-Kee Hong, Jae C. Choe, Eun-Shik Kim, Byung-Sun Ihm and Bong-Seop Kil. *Plenary lecturers and public lectures of the VIII INTECOL International Congress of Ecology*. 2002. The Organizing Committee of 8th INTECOL Congress.
- Dowon Lee, Virginia Jin, Jae Chun Choe, Yowhan Son, Shinjae Yoo, Hak-Young Lee, Sun-Kee Hong and Byung-Sun Ihm. *Ecology of Korea*. Bumwoo Publishing Company, Seoul. 406pages. 2002. The Organizing Committee of 8th INTECOL Congress.
- Eun-Shik Kim, Kwang Ja Bang, Seonmi Cho, Sun-Kee Hong, Byung-Sun Ihm, Byeung-Hoa Kang, Kyo Seok Kang, Bong-Seop Kil, Heiyoung Kim, Kun Ok Kim, Yong Hyun Kim, Bong Sup Lee, Jeom-Sook Lee, Kwang Woo Park and Yeung Ju Yi. *Beautiful Wildflowers in Korea*. GOT & NAMO, Seoul, Korea. 460pages. 2002. The Organizing Committee of 8th INTECOL Congress.

4. OUTCOMES OF THE CONGRESS

4.1 A Seoul Declaration for the Conservation of Natural Environment

At the Closing Ceremony, "*World Ecologists' Declaration for the Harmonious Living of Human Beings and Biosphere in the 21st Century*" was announced and the Congress participants unanimously agreed to urge the world community to enhance such research as LTER (long-term ecological research) for the next generations to come - see below. The importance of LTER was strongly emphasized.

World Ecologists' Declaration for the Harmonious Living of Human Beings and Biosphere in the 21st Century: Seoul 2002

We, the ecologists attending the 8th International Congress of Ecology in Seoul, Korea, are concerned about the destruction, and inappropriate and unsustainable exploitation of ecosystems in the last century. We are committed to provide united guidance for spaceship Earth in this century. We wish to make the 21st Century one of peaceful existence of humans living in dignity within healthy ecosystems. Ecologists in academia, business and government service must reach out to develop cultures that create harmonious relationships between human enterprises and the environment we exist within and depend upon. We are ready to undertake this enormous and vitally important task. We declare the following resolutions in support of the welfare of human kind and the environment in which we live.

1. We urge the World Environmental Summit to have serious and responsible deliberations so that participants will reach a consensus on the directions and solutions necessary to solve the key environmental issues, such as global warming, loss of biological diversity, and deterioration of ecosystem functions.

2. Korea has experienced numerous environmental problems in the last century of rapid economic growth and urbanization. Korea can now emerge as an exemplary

model of sustainable development for other countries. We praise recent initiatives of central government, the Seoul City government, and Korean citizens, as role models of what needs to be done, and how to accomplish the objectives.

3. World communities will be tied closer than ever before the end of this century, as population and economic growth inevitably put even more stress and demands on ecosystems. It is essential to put more efforts into revealing the directions, changes, and evolution of ecosystems and the biosphere into a wide and long-term perspective as these new global and local pressures increase. In this regard, Long-Term Ecological Research (LTER) initiatives should have a high priority because of their proven success and irreplaceable value.

4.2 Formulation of the East Asian Federation of Ecological Societies (EAFES)

After the Congress, the "*East Asian Federation of Ecological Societies (EAFES)*" was formed with initial endeavours among the national ecological societies of China, Japan, and Korea. The mission of the EAFES is to promote academic communication, information exchange, research cooperation, ecological knowledge popularization and capacity building in the area of ecological research, training and consultation among the members from the three ecological societies. The main tasks of the EAFES in the near future include establishing a website, setting up ecological networks, compiling newsletters, promoting mutual or triple cooperative research on common ecological issues, contacting other Asian ecological societies, and in the longer term publishing journals. ESC will be responsible for setting up the EAFES Web in 2003 and the three national societies will provide information for it periodically. The EAFES academic conference will be held regularly every two years and the first East Asian Conference of Ecology will be held in Korea in October 20-24, 2004, at the Mokpo National University, Korea.

4.3 Promotion of National Ecology in Korea

Domestically, the "*Nation's Baseline Ecological Research*" was officially initiated with the sponsorship from the Ministry of Environment, Korea, where the Nation's Baseline Ecological Research can be defined as the long-term and baseline research activities in ecological science which are key to the natural ecosystems of Korea, and which will ultimately provide the decision makers with the systematic and organizational information toward the establishment of rational and efficient policy options for attaining an 'eco-vision' of the nation in the 21st century, in such fields as biodiversity conservation, sustainable development, ecosystem restoration, global environment preservation, etc.

5. THE EPILOGUE

In hosting the Congress, the LOC tried successfully to utilize information technology (IT) and the internet system to make the Congress the most high-tech

meeting in the history of INTECOL. In addition, Seoul is located within one of the world's most dynamic and intellectual cultures, the LOC tried, with many world-renowned speakers and delegates from all over the world, to make the VIII International Congress of Ecology as the site of valuable opportunities to enhance careers as well as chances to exchange new ideas and valuable insights in ecology and the environment. The necessity of international networking and active cooperation in order to solve the environmental problems should be re-emphasized. The International Congress of Ecology in Seoul involved the participation of many international and domestic academic associations. Their roles and strong support were major factors leading to the success of the Congress. Notable examples include the International Association for Landscape Ecology (IALE), which was an important supporter. During the Congress, this group showed new spatial solutions of environmental problems at both the local and the global scale. The Long-term ecological research network (LTER) is another international organization working at both the local and global scale. The new methodologies in several fields of ecology were discussed, especially in consideration of USA and Chinese LTER sites. One of the most valuable outcomes from the 8th International Congress of Ecology was the establishment of the "East Asian Federation of Ecological Societies (EAFES)". This is a most important development for ecologists in the region, leading to much greater cooperation and interchange of ideas. The mutually beneficial activities of EAFES and INTECOL will help such co-operation between ecologists world wide, and will be important in addressing the major ecological problems, which will confront us in the 21st Century.

In summary, hosting the congress contributed to catalyzing interdisciplinary research, technology transfer, and public awareness on the importance of environmental conservation. Moreover, government and academic leaders had a chance to acquire valuable information needed for the development of research policies in ecological preservation and environmental management at the domestic as well as at the international level.

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